LOW COST DBS RECEIVE ANTENNA

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D.I.I.T.

by

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to the

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CERTIFICATE

It is to certify that the work contained in thesis entitled "**A LOW COST DBS RECEIVE ANTENNA** ", by R.K.Joshi has been carried out under my supervision and that this work has not been submitted elsewhwre for a degree.

24 July,1995

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Abstract

An X-band DBS receive antenna design using helical elements for operation at 11.85 GHz downlink frequency is presented in this thesis. The characteristics (impedance, gain, radiation pattern and axial ratio) of the helix element for the array were determined experimentally. An 8 elements linear array (as a test model) was fabricated and its radiation pattern and gain were determined experimentally and based on this, the design of 64 elements planar array is presented. The design is suitable for " Direct to home satellite T V.". The aim of the work was to design a low cost antenna array with approximate gain of 35 dBi and bandwidth of 600 MHz. The feed network for the 64 elements planar array was designed using suspended substrate stripline. This provides more bandwidth and very small radiation loss compared to microstrip and stripline corporate feed. For printing the feed network 0.4 mm thick glass epoxy substrate was used. Overall gain of 28 dBi and axial ratio less than 3 dB for the operating frequency range have been achieved. The approximate size of the proposed array will be $60\times60\times10$ cm^3. This array has merits like low cost, light weight, etc. compared to conventional dish antennas.

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Contents

Chapter 1

Introduction

Direct broadcasting of T.V. programmes by Direct Broadcast Satellites (DBS) was started in early eighties in Japan on experimental basis and within a short span of time it spread over various parts of the world (either on experimental or operational basis). In present days DBS is one of the most promising ways which will completely change the conventional practice of T.V. and Radio broadcasting. Specially round the clock service through DBS has brought DBS receivers in demand. This resulted in mass production of DBS receivers and the price of the commercially available receivers has reduced significantly including the cost of antenna. A brief review of DBS services frequency bands, specifications for DBS antenna and aim of the thesis are given in next paragraphs.

1.1 Satellite Services and Frequency Bands

Basically there are three types of satellite services:-

1. Fixed Satellite Services (FSS)

2. Broadcast Satellite Service (BSS)

3. Mobile Satellite Services (MSS)

FSS and BSS frequency band allocations [11] are depicted in Fig. 1.1:-

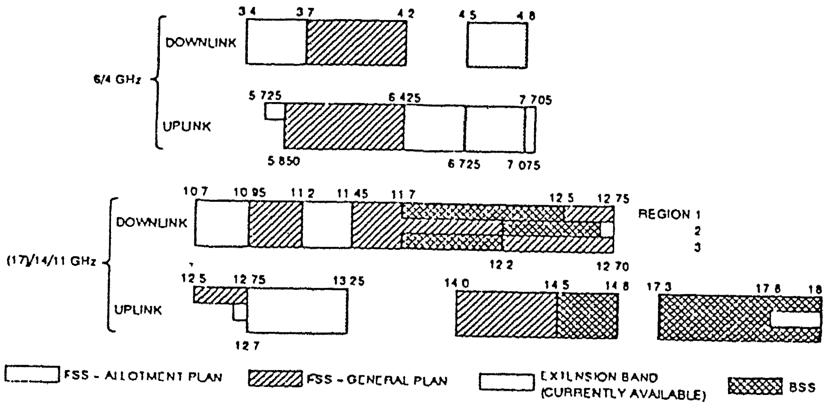


Figure.-1.1 FSS and BSS frequecy band allocations

Since the minimum in orbit separations of broadcast satellites are limited to 6° for BSS and 2° degrees for FSS, satellite transponder power is limited to maximum power flux density of the order of -103 dBW/m^2 /27MHz in order to minimise adjacent satellite interference.

1.2 Specifications for DBS antenna

DBS antennas are designed to meet following specifications:-

1. Frequency range : 11.7 GHz TO 12.2 GHz
2. Polarization : Circular
3. Gain : >33 dBi
4. Axial ratio : <3 dB
5. VSWR : <1.5

Apart from above the antenna should satisfy the sidelobe specification recommended by FCC (explained in chapter:3 section 3.1.1) to avoid undesired reception.

1.3 Aim of the Thesis

In the design of DBS antenna, there are problems of reducing size, weight and cost and it must have high gain (=33 dBi). Several types of DBS antennas been developed and are commercially available in market at reasonable cost of which most attractive are the planar printed arrays. The price of the printed antennas is directly related to the cost of the substrate and connectors. Conventionally printed antennas require a low loss and low dielectric constant substrate. Unfortunately most of the substrates currently being used are expensive. *National Telecommunications of France* has developed a new substrate using polypropylene which exhibit characteristics comparable to RT Duroid 5880, glass reinforced *PTFE*, etc. and it is available at lower prices which helps to lower the cost of the printed antennas.

In this thesis an attempt has been made to reduce the cost of the antenna by using easily available thin glass epoxy substrate (0.4 mm) for printing the feed network and employing high directive helix antennas as array elements.

Chapter 2

Survey of DBS Receive Antennas

Increase in operating effective isotropic radiated power (E.I.R.P.) of DBS satellites has resulted in reduction in antenna size and cost as the production figure has moved up from thousands to millions. DBS requires a circularly polarized antenna with high gain (about 35 dBi) and low axial ratio ($<$ 3 dB). Such technical specifications can be met by conventional reflector antennas However, reflector antennas are rather bulky to handle and their performance sometimes gets degraded due to rain, wind, snow, dust, etc. As an alternative to reflector antennas various types of planar antennas have been studied and developed for DBS reception in 11.1 GHz to 12.2 GHz band. Since Japanese DBS service is the first one and well established in the world, most of the DBS antennas have been developed and marketed in Japan. DBS antennas can be classified into following groups:-

1. Parabolic reflector dish antennas.
2. Printed antennas.
3. Waveguide slot array.
4. Low profile helical antenna array.
5. Curl antenna array.
6. Array of highly directive helixes.

Salient features of each of the above are highlighted in next paragraphs.

2.1 : Parabolic dish antennas.-

Due to high E.I.R.P. transponders employed for DBS, the size of parabolic dish can be as small as 45 cm to 60 cm in diameter. The aperture efficiency of commercially avail-

able antennas ranges from 60 % to 70 % . Due to intrinsic insensitivity to frequencies of both feed horn and dish, one can obtain satisfactory flat response in DBS band, but the upright profile of the offset paraboloid and dish antenna is space effective and sensitive against precipitations (snow, dust, etc.). Further the circular to linear converter attached to antenna between the feed horn and low noise blockdown converter (LNB) increases load on the antenna arm. Reduction of weight and size is an important issue for DBS applications. An extensively used substitute for feed horn is helical antenna with inbuilt quarter wave polarizer [1,2,3].

Dishes are made of either pressed metal or diecast fiber reinforced plastic (FRP). Steel-sheets can also be used with special surface finish such as electro-deposition, zinc phosphate treatment, etc. Offset feed antennas gives superior performance compared to symmetrical front feed paraboloid reflectors with scalar feeds but they are costlier. Therefore later type is widely used. Cassegrain configuration is normally not used because blockage losses becomes excessive as the subreflector diameter has to be 8 to 10 times the operating wavelength and this results in high sidelobes in the radiation pattern which makes it difficult to meet the stringent sidelobe envelope specifications for DBS reception .

2.2 Printed Antennas :-

Printed antennas for DBS reception consists of a large number of radiating elements on one side of the substrate in the form of a two dimensional array. Feed network is printed on the other side of the substrate by employing microstip lines, striplines or suspended lines. Many types of radiating elements have been developed and used in combination with various feed lines. Printed antennas have several advantages such as:-

1. Ease of handling and installation on the wall of houses.

2. Less degradation of performances due to wind, snow, rain, etc.

3. Light weight.

4 Most suitable for electronic beam control and steering.

Main disadvantage associated with printed antennas is that about 2 to 6 dB/m feeder loses in DBS band have been reported depending on the feeder structure and substrate. It is quite important to minimize the losses to obtain high aperture efficiency. Some wellknown configurations of printed antennas for DBS applications are explained in short in the next paras [3,4].

2.2.1 Microstrip line slot array:-

A large number of slot pairs are arranged about one wave length distance along a microstrip line as shown in Fig. 2.1. A reflector is attached at about quarter wave length distance from the substrate surface. Total gain of about 28 dBi from an array of 320 slots has been reported in literature and by employing four such arrays good quality picture can be received.

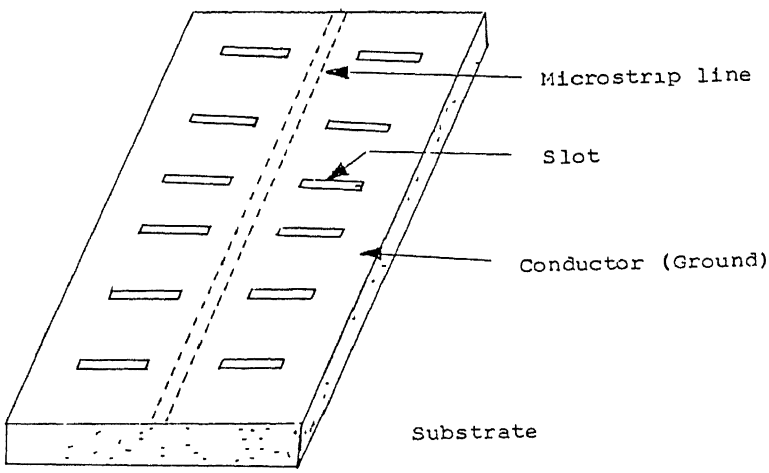


Fig.2.1:microstrip line slot array

2.2.2 Combline array :-

This DBS array consists of many "fingers", a half wave length printed dipoles, attached directly to the microstrip line with spacing of about half guide wave length as shown in Fig. 2.2. For DBS reception at least four such sub arrays (each of about 29

dBi gain) are required for good quality reception. Main disadvantage of this type of array is poor aperture efficiency (approx. 20 %).

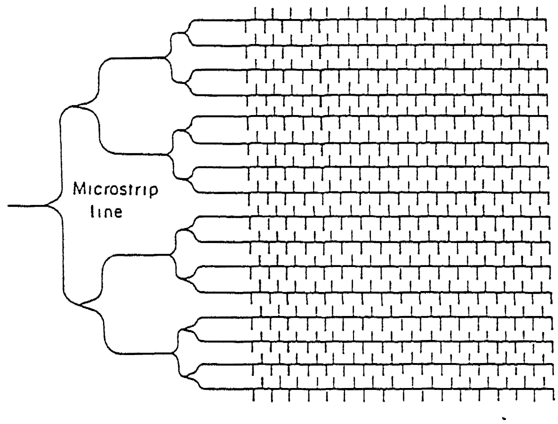


Fig.2.2: combline array

2.2.3 Crank type microstrip line array :-

The basic structure of this type antenna is made up of two crank-type microstrip lines which are placed to have a half period shift. The dashed part in the Fig.2.3 shows the fundamental radiating element. This type of antenna is commercially available in Japan. The latest model consists of 332 fundamental elements on a foamed polyethylene substrate. Each pair of the microstrip line is terminated with a square patch to improve the antenna efficiency. The size of the array is about 640×430 mm and maximum gain of about 34 dBi, aperture efficiency of about 62 % have been reported.

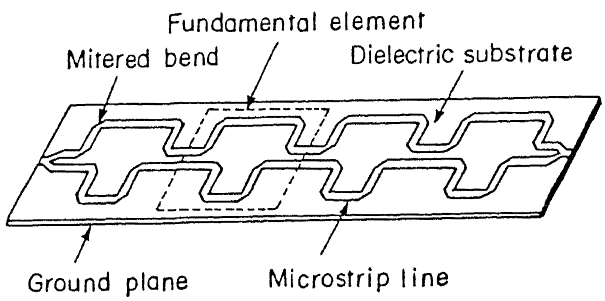


Fig.2.3: Crank type microstrip line array

2.2.4 Flat folded dipole array :-

The basic radiating element is composed of two symmetrical flat folded dipoles made in a top metallic plate. The folded dipoles are fed by a corporate feed of strip line, laid between the top and the bottom metallic plates. Round shaped windows around the flat folded dipoles are designed not to deteriorate the stripline characteristics.

The gain of about 37 dBi and aperture efficiency of nearly 50 % could be achieved with a large array containing 1024 elements symmetrically placed on a conventional substrate of 1 59 mm thickness The element spacing was kept approximately 0.89 of free space wave length. The configuration is shown in the Fig. 2.4.

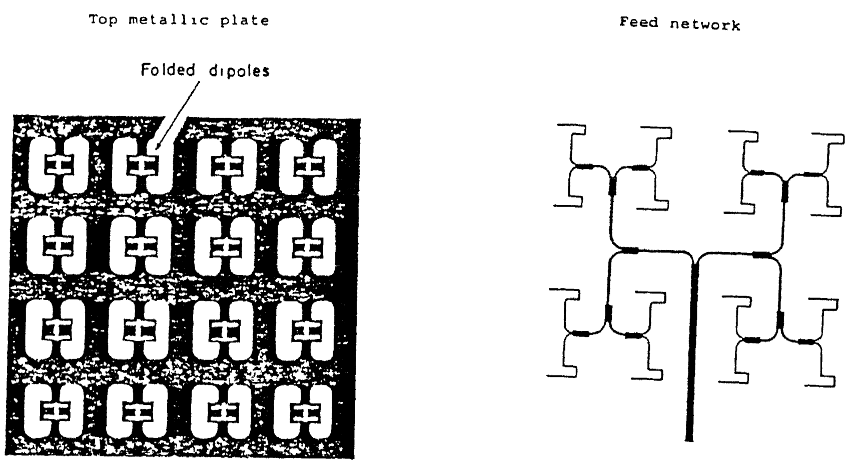


Fig.2.4: Folded dipole array

2.2.5 Rectangular slot array :-

This antenna consists of a triplate structure supported by honeycomb foam spacers to minimize feeder losses. The radiating element in a top metallic plate consists of a rectangular slot with a hexagonal patch fed by electromagnetic coupling to the strip line as shown in Fig. 2.5. The basic radiating element of this antenna seems to be complementary to a square patch with a diagonal slot for circular polarization. A commercially available model of this type of array in Japan contains 384 elements arranged

on a triplate structure of size $420mm \times 600mm$. It provides a gain of 34 dBi and aperture efficiency of 65 % . A larger sized antennas ($780mm \times 780mm$) are also available with 35.5 dBi gain and 12° degree beam tilt.

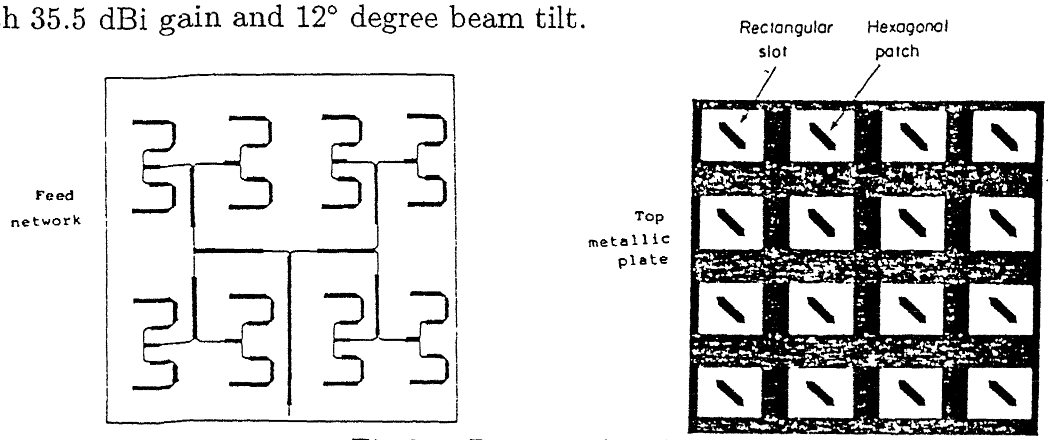


Fig.2.5: Rectangular slot array

2.2.6 Suspended circular patch array :-

This type of antenna consists of two metal plates and a suspended thin film substrate between the plates. About 1 mm air gap is maintained between the substrate and each metallic plate as depicted in Fig. 2.6. This arrangement reduces feeder losses considerably. Circularly polarized patches with a single feed point and the feed lines are printed on the film substrate. Circular slots are opened on the top metallic plate for reception of the signal. The commercially available array consists of 476 elements printed on a $556mm \times 476$ mm substrate. This gives a gain of 34.1 dBi and a beam tilt of about 10°.

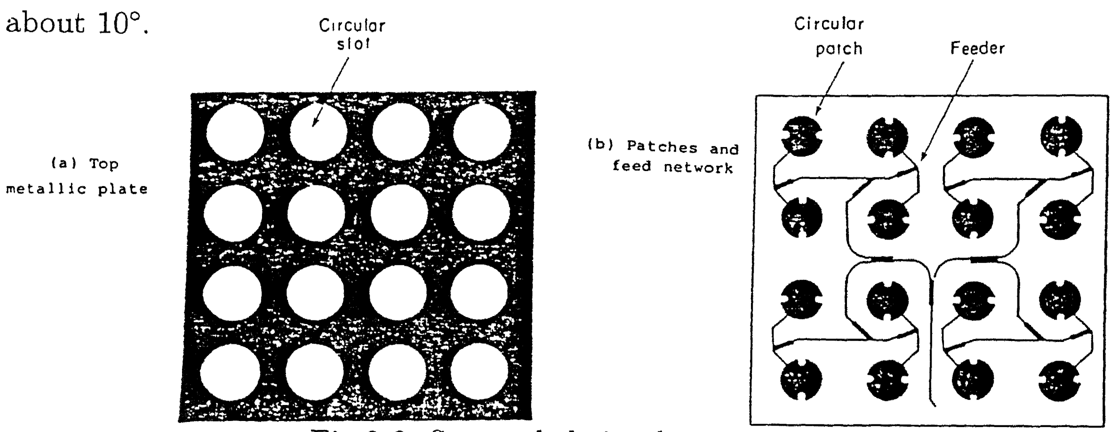


Fig 2.6: Suspended circular patch array

2.3 Wave guide slot array :-

The feeding component of wave guide slot array consists of a radial wave guide or rectangular wave guide . The feeder losses in such waveguides are negligible and high aperture efficiencies of about 70 % to 80 % can be achieved. Commonly used slotted structure is Radial line slot array. The constructional details of the array are shown in Fig.2 7 [5].

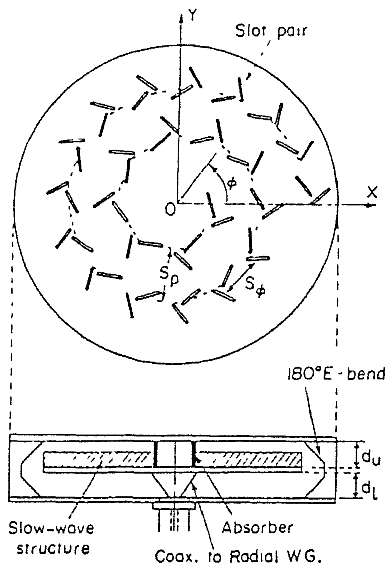


Fig.2 7: Waveguide slot array

Three plates (equally spaced by distance d) forms a twofold radial line waveguide. The top plates acts as aperture with slots. The r.f. power is fed at the center $\rho = 0$ of the lower waveguide and a radially outward travelling wave is generated. At the outer edge of the waveguide $\rho = \rho_M$, it is transformed into a radially inward travelling mode in the upper waveguide . Slots pairs are excited by the inward travelling wave and provide a circular polarization. Most of the r.f. power gets radiated through the slots while the remainder gets absorbed by the dummy load (absorber) placed at $\rho = \rho_m$. The outer edge of the waveguide and the feeding point have 45° tapered structure so as

to suppress the reflection from them Slots pairs are arranged on the top plate along a spiral. The distances S_ρ and $S_\circ$ must be smaller than the free space wave length ($\lambda_\circ$). A slow wave may also be installed inside the upper waveguide to suppress the grating lobes Design parameters for a typical DBS antenna are given below:-

Diameter of the antenna D	= 0.6 meter
ρ_M	= 0.3 meter
Location of the absorber ρ_m	= 0.06 meter
Spacing between plates d	= 0.0075 meter
Distance between slots δ	= 0.001 meter
Length of the slots 2L	= 0.0125 meter
Radial spacing between two slots $\frac{S_\rho}{\lambda_0}$	=1.0
Angular spacing between the slots $\frac{S_0}{\lambda_0}$	=0.7
total no. of slots N	=1238

The structure is supposed to give a gain of about 36.3 dBi and 76% aperture efficiency The gain and efficiency for this type of antenna are related by:

$$\eta = (\lambda_0/\pi * D)2G \tag{2.1}$$

If a slow wave structure is provided then S_0 and S_ρ reduces while the number of slots increases for a given D, ρ_M, ρ_m, d and δ.

2.4 Low Profile Helical Array :-

A two turn 4 degree pitch angle helix is used as radiating element for this type of the array [6,7]. The feed wire of each of the helix is inserted into a radial wave guide through a small hole and excited by travelling wave propagating in TEM mode in the radial wave guide. The design features of the array and the element are presented in the following subsection.

(i) Design data for the low profile element:-

Pitch angle α	$= 4^\circ$
Helical circumference C_λ	= one wave length(2.54 cm at 11.85 GHz)
Wire dia d	= 1 mm
	= 0.04 of free space wave length
Number of turns	= 2
Bending height h	= 0.05 of free space wave length

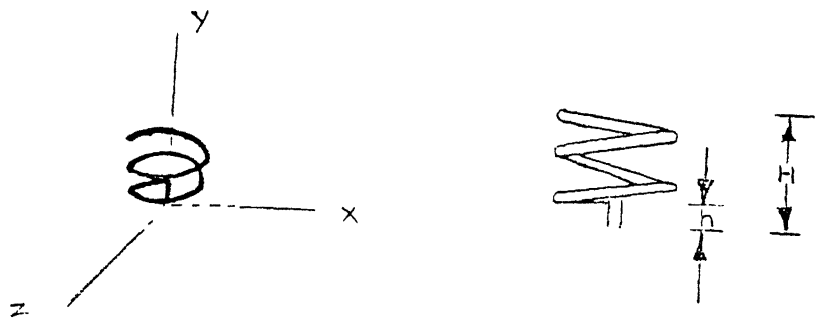


Fig.2.8: Low profile helix element

It is found that long helix (about 10 turns) with low pitch angle ($\alpha \approx 4^\circ$) gives a poor axial ratio while a two turn helix produces a axial ratio of about 0.5 dB to 3 dB with a bandwidth of 10 % to 12 %. The 3 dB beamwidth for such an element is found about 70° degrees and radiation pattern is given by $E = (\cos\theta)^{1.7}$. The input impedance is found $Z_{in} \approx 70.0 + j30.0\Omega$ in the DBS band. Antenna gain about 9 dB has been found experimentally in 11 GHz to 12 GHz frequency rang.

(ii) Low profile array :-

The low profile helical elements are arranged to form a circular flat array. The radial and circumferential spacings between the elements is as shown in the Fig. 2.9.

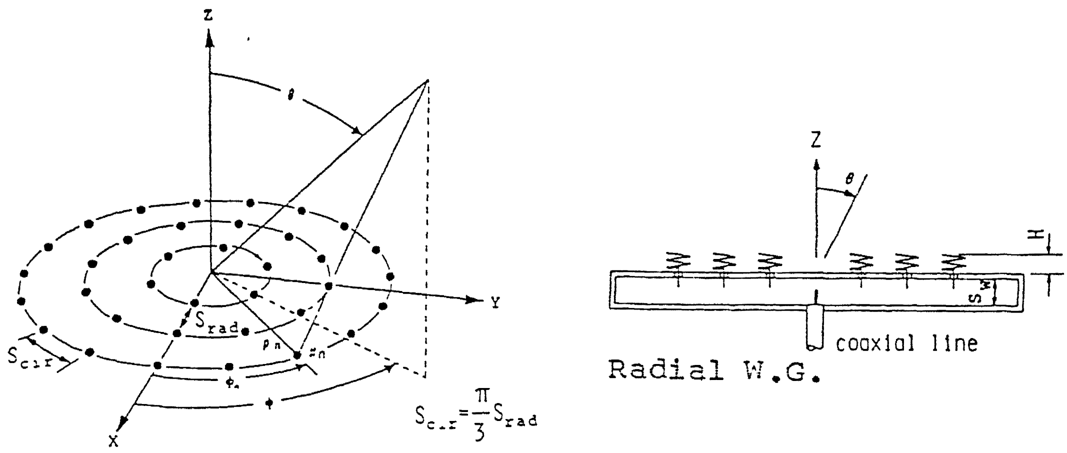


Fig.2.9·Low profile helical array

The elements are inserted into the radial wave guide through small holes made in the teflon bushes. The spacing between the plates of the wave guide is kept sufficiently small compared to the operating wave length (approx. 7.5 mm =0.3 of the free space wave length). Ideally the field distribution in the wave guide should have only forward travelling wave propagating from the centre towards the wave guide end and the backward travelling wave from the wave guide end is to be eliminated. It was observed that a backward travelling wave is present dueto existence of the fraction of forward travelling wave at the end of the wave guide. This reflection is minimized by inserted feed wires at the outer most helixes at adistance of quarter wave length from the edge of the wave guide, where the standing wave maxima exists. Most of the reflected power is absorbed by the outermost helixes and the backward travelling wave becomes negligible over the wave guide except at end. The depth of insertion of each of the element in the wavegude is adjusted for uniform power distribution over the surface of the array. Since the forward travelling wave decays as it progresses towards the end of the waveguide, the depth of insertion is increased gradually as the radial distance increases.

The radial and circumferential distances S_{rad} and S_{cir} are related by:-

$$S_{rad} = (\pi/3) * S_{cir} \quad (2.2)$$

For an array of about 35 dBi gain total 396 elements are required to be arranged over the surface of the radial waveguide of 46 cm dia. and thickness of 7.5 cm. Design parameters for this type of array are given below:-

Overall gain of the array	= 35 dBi
Gain of individual element	= 9dBi
Total no. of elements	= 400 (aprox.)
Half power beamwidth β	= $3.7°$ to $4.2°$
Aperture efficiency η	$= \frac{G_{mes}}{\frac{\pi D_a}{\lambda}^2 \cos\theta_0}$

Where G_{mes} is the array gain measured at beam tilt of $\theta°$, D_a is dia. of array surface = 2(no. of rings with S_{rad})+ edge space of about $\frac{S_{rad}}{2}$. and λ is operating wavelength and $\theta°$ is the beam tilt. Aperture efficiency of 60% to 80% have been reported for beam tilt of 0° to30°.

2.5 Curl Antenna Array :-

A high gain DBS receiving antenna with very high aperture efficiency (= 95 %) can be realised by employing curl radiating elements. Attractive features of the curl element and the array are given in the next subsections [8].

(i) Curl antenna:-

The configuration of the antenna is shown in Fig. 2.10.

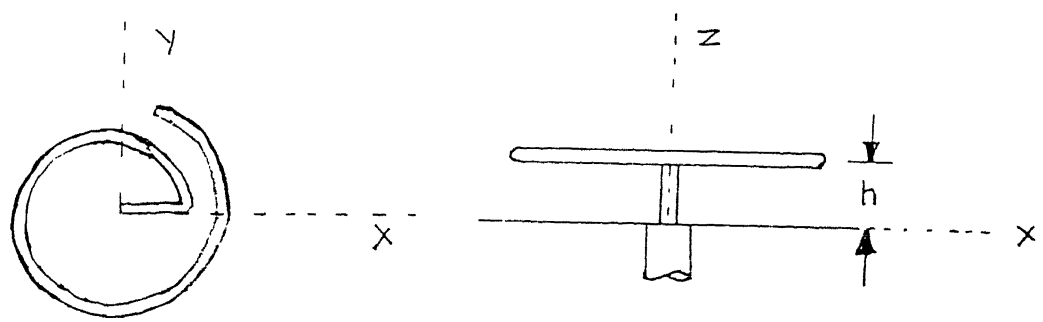


Fig.2.10: Curl element

It is an open arm antenna with radial distance from the centre $r_c = a * \phi$ where 'a' is the spiral constant and ϕ is the winding angle starting at ϕ_{st} and terminating at ϕ_{end}. For DBS applications following design data have been proposed [8]:-

Wire dia. d	$= 0.6$ mm
	$= 0.0185\ \lambda$
Spiral constant a	$= 0\ 18$ mm/rad
	$= 0.00711\lambda$/rad.
Starting angle ϕ_{st}	$= 6\ \phi$ rad

(λ is the free space wavelength)

Since ϕ affects axial ratio directly , an optimum value is determined experimentally for given height 'h' of the curl. Normally 'h'=3.8 mm and ϕ_{end} =26.3 rad are used. It has been experimentally established that a gain of 8.4 dB, axial ratio within 3 dB and HPBW of the order of 70° are achievable with 6.7% operating bandwidth over the entire DBS band and resistive part of the input impedance is found about to be about 120Ω.

(ii) Curl Array:-

Several curl elements are arranged over the surface of a radial waveguide as shown in the Fig. 2.11. The radial and circumferential distances are related by :-

$$S_{cir} = (\pi/3) * S_{rad}. \tag{2 3}$$

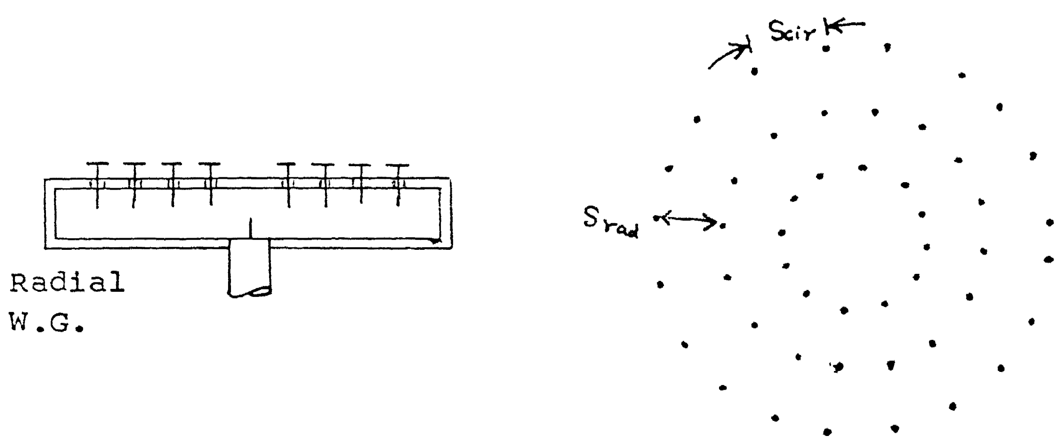


Fig:2.11 Curl array

For a given gain of the array the number of elements are determined and positioned according to the Eqn. 2.3 The effective area and aperture efficiency are given by:-

$$\eta = \frac{A_{eff}}{A} \tag{2.4}$$

where $A_{eff} = \frac{G_d \lambda^2}{4\pi}$ and G_d is the directivity evaluated using approximated radiation pattern of the element (i.e. $\cos(0.571 * \theta)$).The distance between the lower and upper plates of waveguide is kept less than half wavelength at the operating frequency so as to allow TEM mode to propagate towards the edge of the cavity. The uniform power distribution is achieved by appropriate control of the insertion lengths of the elements, while the excitation phase is controlled by the mechanical rotation around the axis of the elements.

2.6 Array of Highly Directive Helixes :-

In all the above types of DBS arrays a large number of elements (typically above 400 elements) are required to achieve reasonable gain (34 dBi). If highly directive elements are used than the total number of elements can be reduced for a given gain of the array . This leads to a simple feeding structure and the loses associated with the feeding system can be minimized.

In this thesis a DBS array based on the above idea proposed. The use of highly directive helixes as radiating elements feed by suspended stripline feeder structure is proposed. Details of the same are presented in the following chapters.

Chapter 3

Design of the array

3.1 Design approach :-

After the development of DBS services, the design of the receiver antenna has always been into limelight The antenna is designed keeping in view the technical specifications, ease of manufacture, and ultimate cost. The design approach for the proposed DBS antenna is based on following considerations:-

1. Electrical considerations.

2. Mechanical considerations.

3. Economical considerations.

3.1.1 Electrical considerations:-

Electrical considerations includes following factors:

- Specifications of the array.
- Selection of the element.
- Selection of the substrate.
- Selection of the feed structure.
- Sidelobe consideration.

Each of the above is highlighted with respect to the proposed design.

Specifications of the array :-

The design of the proposed array is intended to meet following specifications:-

Frequency rang	: 11.5 GHz to 12 GHz
Bandwidth	: 0.5 GHz
Gain of the array	: > 33 dBi
VSWR	: < 1.5
Polarization	: Circular
Axial ratio	: < 3 dB

Selection of the radiating element :-

Normally microstrip array, low profile helix array, curl array, etc. require very large number of radiating elements and the feed becomes complicated. Therefore to reduce the number of elements and to simplify the feed network highly directive helix was chosen for the proposed array as array element. This is suitable for reception of circularly polarized wave also. the design of the element is given in the next chapter.

Selection of the substrate:-

Since the cost of the antenna is directly related to the cost of the substrate, the selection process is a compromise to get the best balance between the desirable properties for the aspecification application and cost. Apart from this there is a range of mechanical, electrical, thermal and chemical criteria to be taken into account. Since the substrate acts as a wave conducting medium, the quantities like relative permittivity(ϵ_r), dielectric loss factor ($\tan\delta$) and substrate thickness affects the circuit parameters (i.e. characteristic impedance, phase velocity, attenuation coefficient). The variations of he dielectric constant and loss tangent with temperature and frequency are also taken into account. The moisture absorption is also an important parameter as it adversely affects the electrical properties. Moisture penetration can lead to corrosion of the conductor

traces and degradation of the bond between the conductor and the substrate. Moisture absorption can arise due to presence of pores in the substrate. Apart from above the bond of the foil to the substrate must be able to withstand soldering and other lead attachment processes to minimize the damages during the assembly operations.

The survey of various substrates was made keeping in view the factors like low ϵ_r, low loss tangent (tanδ) and lowest possible cost. The glass epoxy (copper clad) substrate (with 0.4 mm thickness) was selected for printing the feed network . However it is lossy and can not be compared with RT-Duroid 5880, RT Duroid 6010, Cuflon, etc. but compared to the commercially available gloss epoxy substrate of 1.6 mm thickness it is less lossy. A list of some substrates and their important properties are given in the appendix A1.

Selection of the feed structure :-

Transmission lines are the integral part of the feed network. Therefore the design of the feed structure solely depends on the type of the transmission line employed. For designing the feed network for the proposed array, Suspended Strip Line (SSL) was selected. It is the most usefull variant of the strip line. Some basic features of the same are given discussed here. The constructional details of SSL are shown in the Fig.3.1.

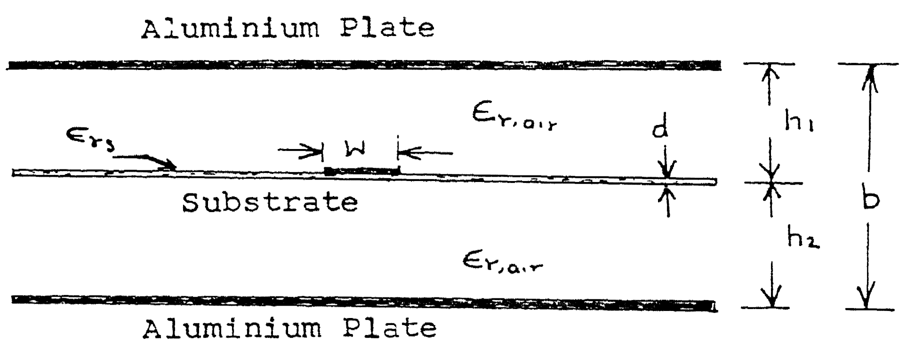


Fig.3.1: Suspended substrate strip line

Basically it is an inhomogeneous line in which the substrate carrying strip is placed

symmetrically between the ground planes, thereby leaving an equal air gap on either side of the substrate. By choosing the substrate sufficiently thin, the effective dielectric constant can be made close to that of air; thus increasing the frequency rang of the operating dominant mode which is nearly TEM. The dimensions of the structure are carefully chosen so as to avoid the propagation of the undesired waveguide mode. The characteristic impedance of the line is given by [9]

$$Y_0 = \epsilon_0 \left[\coth \beta(b-d)/2 + \frac{\coth \beta(b-d)/2 \coth(\beta d) + \epsilon_r}{\epsilon_r \coth \beta d + \coth \beta(b-d)/2} \right] \tag{3.1}$$

Introducing the air gap between the dielectric substrate and the ground plane helps to reduces the effective dielectric constant and consequently the strip dimensions becomes nearly two to three times wider than microstrips for the same characteristic impedance. Thus higher impedance values can be realized compared to microstrips and striplines. A qualitative comparison among stripline, microstrip line and suspended strip line is given below [9,10]:-

Type of line	Normal impedance range(Ω)	Q factor	Radiation loss
Strip line	20-120	≈ 500	Nil
Microstrip line	20-100	≈ 250	low
Suspended strip line	25-150	high	Nil

Finally suspended stripline was chosen as the medium for feeding network as it offers advantages of realization of higher impedance values, high Q, small dispersion and lower transmission loss compared to strip line or microstrip using the same dielectric substrate.

Side lobe consideration :-

Normally small aperture antennas have broad radiation pattern and high side lobe level which results in interference due to adjacent satellites. CCIR standards for side lobe envelope defines the sidelobe gain envelope as[1,11]:-

$$G(\theta) = (32 - 25 \log \theta) dB \tag{3.2}$$

where θ is in degrees.Similarly FCC specifications for side lobe gain envelope requires that, for $\theta > 7^\circ$

$$G(\theta) = (32 - 25log\theta)dB \tag{3.3}$$

and for $0^\circ < \theta < 7^\circ$

$$G(\theta) = (29 - 25log\theta)dB \tag{3.4}$$

The DBS array is designed to meet the above side lobe requirements to avoid undesired reception due to adjacent satellites. For this, highly directive helix is proposed as an element of the array.

3.1.2 Mechanical considerations :-

Mechanical considerations includes factors like total no. of elements in the array, ease of repairing, heat transfer, weight of array, effect of weather (snow, dust, rain, etc.), ease of installation, etc. The number of elements should not be too large as it increases the complexity of the feed .

While soldering the elements to the printed feed the heat removal /heat transfer should be fast enough so that the printed strips near soldered joints do not come out.

The overall structure should be as simple as possible and it should facilitate reliable fabrication and repair of the array, in case of any damage.

3.1.3 Economical considerations :-

Apart from features like light weight,ease of manufacture, wider bandwidth,etc. the most important is the cost of antenna. It must be as low as possible and acceptable to the DBS users.In the proposed array the COST factor motivated the search for cheap substrate and ultimately thinnest commercially available glass epoxy substrate (0.4 mm thickness) was chosen.

3.2 Element design :-

In the proposed array ,helical antenna is used as array element. The design problem for the element was divided into two parts. First the design of element and second the design of the feed for the element. The impedance matching section was incorporated into the feed itself. The design of the helix element was based on following parameters:-

(1) Radiation mode (2) Beamwidth
(3) Gain (4) Terminal impedance
(5) Axial ratio

Radiation mode :-

It is used to describe the farfield pattern of helical antenna. Broadly it is classified into two types, axial mode of radiation and normal mode of radiation. Proper mode of radiation is selected by choosing the dimensions of the helix appropriately. The dimensions of the helix are conveniently illustrated by a diameter v/s turn spacing chart given in Fig. 3.2 and corresponding modes of radiation are also indicated [12,13].

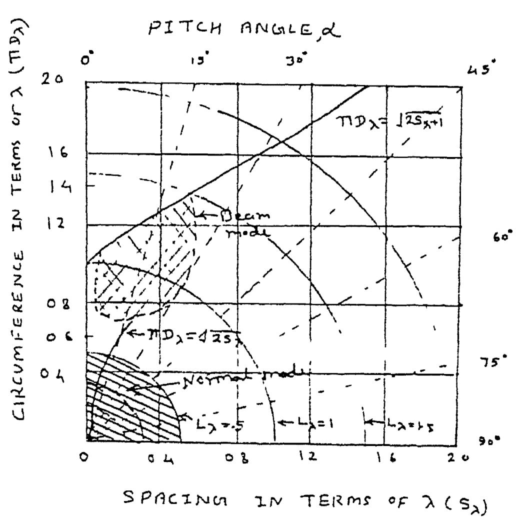


Fig.3.2: Diameter v/s turn spacing chart

The conditions for Normal mode of radiation are listed below [12,13] :-

Condition	: Radiation
S=0 and $\alpha = 0°$	: Linear polarization
S>0 and $\pi D > \sqrt{2S\lambda}$	: Elliptical polarization with major axis of polarization ellipse horizontal
π D=$\sqrt{2S\lambda}$	: Circular polarization
$0 < \pi$ D $<\sqrt{2S\lambda}$	:Elliptical polarization with major axis of polarization ellipse vertical
π D = 0 and α=90	: Linear polarization(vertical)

The condition for axial mode of radiation is determined by considering that the N turn helix is composed of N isotropic point sources spaced by turn spacing S as shown in Fig. 3.3 [12,13].

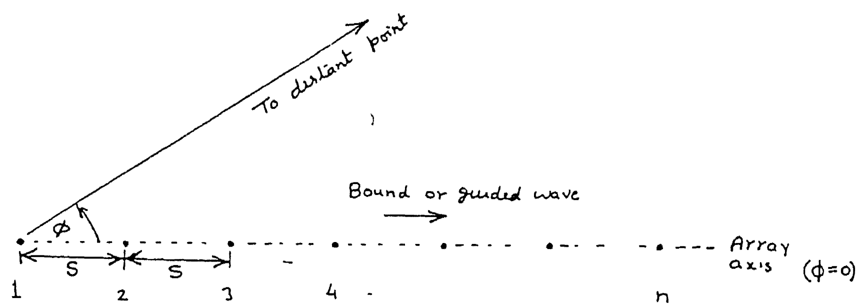


Fig.3.3: Helix as linear array of point sources

The array factor for this arrangement is given by,

$$F(\phi) = \frac{\sin(n\psi/2)}{\sin\psi/2} \tag{3.5}$$

where, $\psi = \beta\cos\phi + \delta$ and

$$\beta = 2\pi/\lambda$$

and δ is the phase difference between adjacent point sources.Therefore,

$$\psi = \frac{2\pi}{\lambda}(S\cos\phi + \mathrm{L/p})$$

$$= 2\pi(S_\lambda\cos\phi - L_\lambda/p)$$

Where 'p' is the relative phase velocity factor of the wave propagating along the helix. For the fields due to each point source to be in the same phase along $\phi = 0^0$ direction (axis of the helix) and assuming that increased directivity condition exists,

$$\psi = -(2\pi * m + \pi/n)$$

where m = 0,1,2,3,....The negative sign is introduced due to the fact that phase of the field due to point source 2 is retarded by $2 * \pi * L_\lambda/p$ with respect to source 1 and so on .

From above ,

$$-(2 * \pi * m + \pi/n) = 2\pi * S_\lambda - \frac{2\pi * L_\lambda}{p}$$

$$\Rightarrow p = \frac{L_\lambda}{S_\lambda + m + 1/2n}$$

for $m = 1$

$$\Rightarrow p = \frac{L_\lambda}{S_\lambda + \frac{2n+1}{2n}} \tag{3 6}$$

$$p = \frac{1}{\sin\alpha + \frac{2n+1}{2n} * \frac{\cos\alpha}{C_\lambda}} \tag{3.7}$$

The condition of axial mode of radiation is that 'p' for the designed helix should be about 0.76. Based on alarge number of experiments performed by J.D.Kraus during 1948-49 and D.E.Baker in 1980 [12,13] following quasi-empirical relations for design of 12 to 14 degree helixes were derived:-

- Half power beamwidth (HPBW)

$$\beta \approx \frac{52}{C_\lambda * \sqrt{nS_\lambda}}$$

- Directivity

$$D = 15C_\lambda^2 * n * S_\lambda$$

(disregarding the effect of minor lobes)

OR,

$$D \approx 12 C_\lambda^2 n S_\lambda$$

- Radiation resistance :-

  For axially feed helix:-

$$R \approx 140 C_\lambda \pm 20\% \Omega$$

For peripherally feed helix:-

$$R \approx \frac{150}{\sqrt{C_\lambda}} \pm 10\% \Omega$$

- Axial ratio :-

$$AR \approx \frac{2N+1}{2N}$$

Above relations were straightway used to design of the helix antenna. Based on above following dimensions were decided.

Diameter of the helix D	$= 0.335\lambda$	$= 7.5$ mm
Circumference C	$= 1.055\lambda$	$= 23.5$ mm
Pitch angle α	$= 13°$	
Spacing S	$= 0.22\lambda$	$= 5.5$ mm
No. of turns N	$= 14$	
Theoretical gain G	$= 17$ dBi	

It was experimentally found that the size of the conductor is not critical and the characteristics of antenna remains almost unchanged in the range of dia of conductor from 0.005λ to 0.05λ . Hence diameter of the helix wire d = 1.5 mm was chosen. Since the terminal impedance of the helix is found about 140Ω , it is

to be matched to standard input impedance 50Ω. The matching section can be provided either by using printed line matching section or by providing a tapered matching section in the helix wire itself. In the first case it is very difficult to print a high impedance matching section as the width of line becomes too small (of the order of 0.2 mm to 0.3 mm for the proposed case employing a glass epoxy substrate (0.4 mm thick and ϵ_r =3.8). Next the possibility of providing the matching section in helix conductor itself was investigated. The experimental model as shown in Fig 3.4 was prepared.

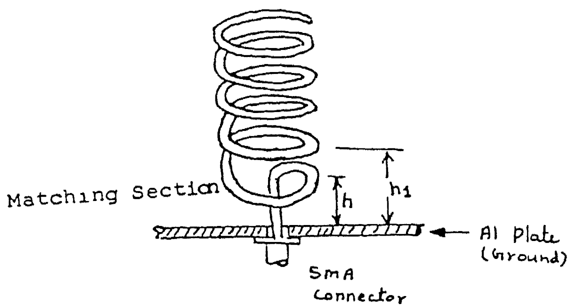


Fig.3.4 Helix with inbuilt matching section

The height 'h' was determined by using the formula of single conductor above ground plane as mentioned below [14]:-

$$Z_0 = 59.95 \ln \frac{2h}{d} + \sqrt{\frac{4h^2}{d^2} - 1} \tag{3.8}$$

From which,

$$Z_0 = 59.95 \ln x + \sqrt{x^2 - 1} \tag{3.9}$$

where x =2h/d and 'd'is dia. of the conductor. For the helix conductor of dia.'d'= 1.5 mm the height for 140Ω characteristic impedance 'h1'=3.9 mm and for 50Ω impedance 'h2'=1.38 mm were calculated using above formula. Then a tapered transformation section with heights 'h_1' and 'h_2' was made at the end of the helix. A VSWR of 1.45 (S_{11}=-15 dB) was obtained. It was experienced that the

arrangement was very critical and sensitive to slight changes in h_1 or h_2 . Therefore it was very difficult to make such matching section manually in all elements of the array at 11.85 GHz. Ultimately it was decided to use suspended strip line matching section for the helix and the impedance at the junction of suspended stripline and helix terminal was measured. It was then matched for minimum possible reflection. The setup used is shown in Fig.3.5.

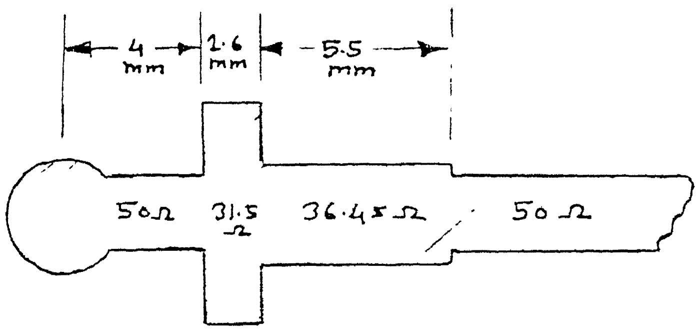


Fig.3.5: SSL matching section for the helix

Since the helix is a wide band antenna, band width of the element is limited due to transitions and hence the use of suspended stripline(SSL) was found a better choice as it provides better bandwidth compared to micro strips and striplines. Details of the element (impedance, radiation pattern, axial ratio, etc.) are given in the next sections.

3.3 Array Design :-

Normally aplaner array for DBS requires overall gain of more than 35 dBi.The proposed array was designed for a gain of 35 dBi. Assuming 90 % aperture efficiency the gain is given by:-

$$G = \eta_a \frac{4\pi A_e}{\lambda^2}$$

where G is gain of array , λ is wavelength , A_e is aperture area. and η_a is

aperture efficiency.

$$\Rightarrow A = \frac{G\lambda^2}{4\pi\eta_a}$$

For G = 35 dBi, A_e = 45 $\times$ 45 cm^2 assuming η_a=90%. If each element of array has a gain of 'g' than the total number of elements 'n' required is given by:-

$$n = \frac{G}{g}$$

If the aperture area is divided into 'n' cells (each of area 'a'= A/n) then the elements are located at the centres of each square cell as shown in fig.(3.6) and distance between elements is given by square root of the cell area.

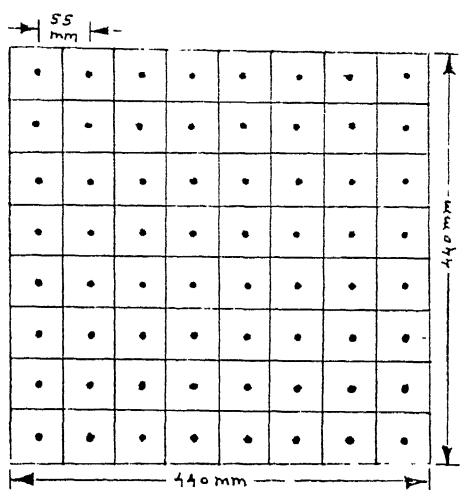


Fig.3.6:Locations of elements on the planar array

For G =35 dBi and g =17 dBi following parameters were obtained:-

Aperture area A	= 45 $\times$ 45 cm^2
Number of elements n	= 64
Area of each cell a	= 31.64 cm^2
Distance between elements d	= 5.5 cm

The proposed square array can be considered as a linear array with each element represented by each row (or column) of the array. Thus principles of linear array analysis can be extended for two dimensional array with slight modifications. For a M $\times$N elements 2-D array with uniform excitation and same phase the array factor is given by:-

$$F(\theta, \phi) = \frac{1}{M} \frac{\sin M\psi_x/2}{\sin \psi/2} \frac{1}{N} \frac{\sin N\psi_y/2}{\sin \psi/2} \tag{3.10}$$

here M is number of elements in x-direction and N is number of elements in y-direction. and

$$\psi_x = 2\pi d_x (\sin\theta\cos\phi - \sin\theta_0\cos\phi_0)$$

and

$$\psi_y = 2\pi d_y (\sin\theta\sin\phi - \sin\theta_0\sin\phi_0)$$

For d_x =d_y = 2.1725 λ = 5.5 cm grating lobes appear, as shown in the plot. However the appearance of grating lobes is of less concern as the highly directive elements are proposed for the array. When the element pattern is multiplied by the array factor the effect of grating lobe is reduced considerably. The side lobe levels are below 15 dB in the theoritical pattern as shown in the attached plot. The improvement in side lobe reduction can be achieved by nonuniform aperture distribution.

Pattern of 1$\times$8 elements linear array with inter element spacing of about d = 2.1725 λ can be regarded as element pattern for the 8 $\times$ 8 planar array. The array pattern of 8$\times$8 elements array is just the square of the 1$\times$8 linear array pattern. To reduce the side lobe levels the excitations of each row (or column) can tapered but it increases beamwidth. With proper excitation levels of each row (or column) desired sidelobe reduction can be achieved up to certain extent. Several synthesis

techniques are available in the literature for calculation of excitation coefficients [14,15].

For a uniformly excited linear array the half power beam width is given by (in radian) [15]:-

$$\theta = 0.886 * \frac{\lambda}{L} \csc \theta_0 \tag{3.11}$$

where $\theta_0 = 90°$ for the broadside array

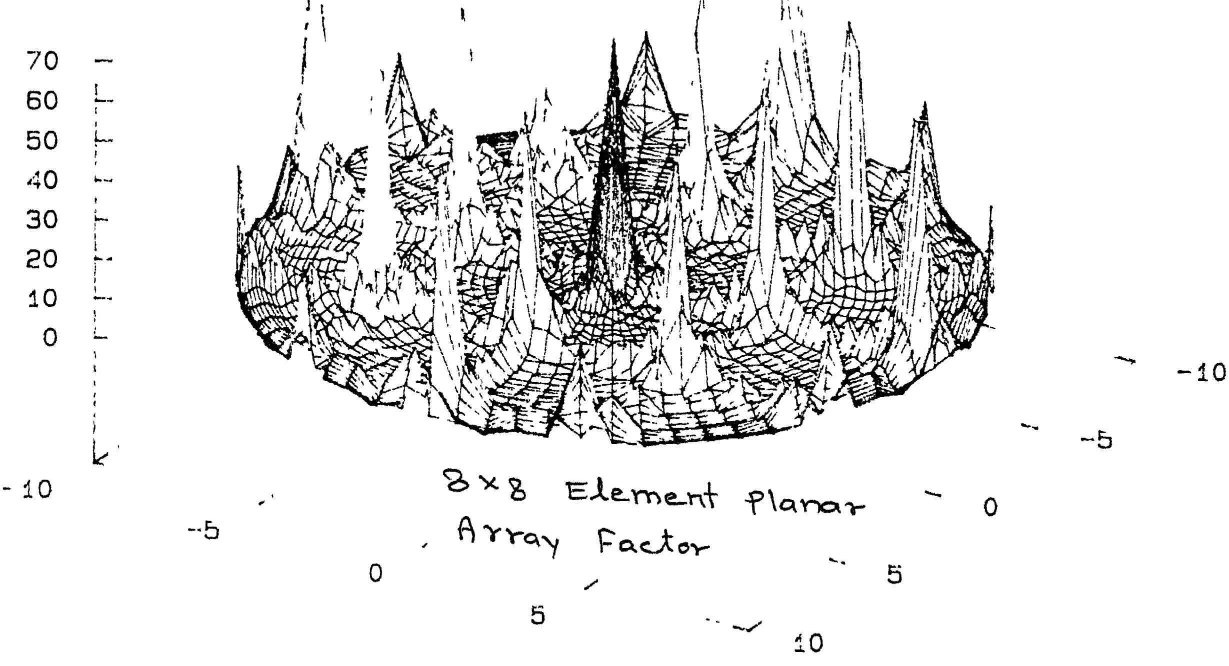
If nonuniform distribution is used to reduce the sidelobe level, the 3 dB beamwidth increases. Curves for the beam broadening factor (a measure of increase in 3 dB widthwidth) for a given sidelobe level are available in the standerd literature [13,14].

In general the 3 dB beamwidth and directivity are related by [12]:-

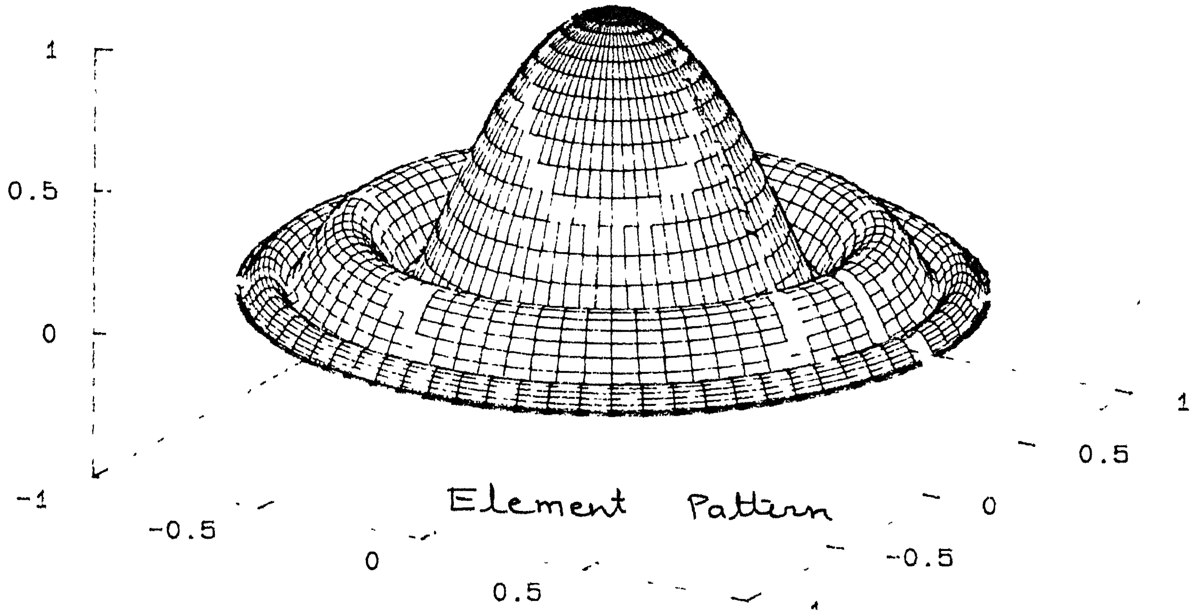
$$D = \frac{41000}{\theta_H * \theta_V} \tag{3.12}$$

where θ_H andθ_V are 3 dB beamwidths in the two principle planes.

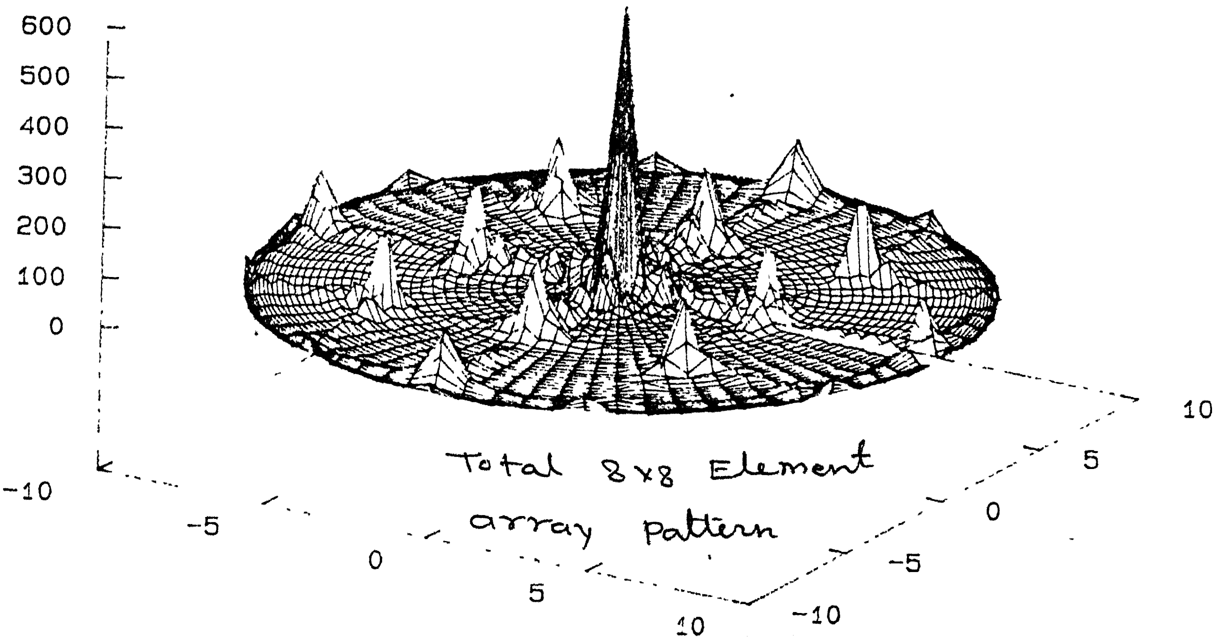
Since the broadside-broadside uniformly fed cophasal planar array produces a sharper main beam perpendicular to the array plane and it requires a simpler feed structure, it was accepted for the proposed DBS array.Further by employing high directivity helixes the effect of grating lobes and side lobes is reduced effectively. Therefore the Dolph- Chebyshave distribution was not incorporated. Proper tapered distribution provides the required side lobe reduction but it broadens the main beam pattern slightly. Since it is a receiving antenna and the chances of interference due to adjacent satellites through the sidelobe directions at the operating frequency are very less, uniformly distributed feed was adopted.



8×8 Element planar Array Factor



Element Pattern



Total 8×8 Element array pattern

3.4 8×8 elements Planar array design for DBS reception :-

Designe of the array based on the forgoing discussion is presented below:-

(a) Design data for the array :-

Size of the array	: 60×60 cm^2
Aperture area (corresponding to 35 dBi gain)	: 45×45 cm^2
Spacing between elements $D_x = D_y$	: 5.5 cm
No of rows	. 8
No. of columns	: 8
No. of elements in each row and column	: 8
Total no. of elements	: 64
Gain of element	. 17 dBi (theoretical)
Type of feed	: uniform distribution using SSL on glass epoxy substrate of 0.4 mm thickness.

(b) Design data for the array element :-

Type of the element	: high directive helix
Diameter of the conductor	: 1.5 mm
Diameter of the helix	: 7.5 mm
Circumference C	: 23.56 mm
Spacing between turns S	: 5.5 mm
Pitch angle α	: 12°
Total no. of turns 'N'	: 14

(c) Array factor :-

The array factor is as shown in the attached plot .

(d) Element pattern :-

The element pattern is as shown in the attached plot.

(e) The radiation pattern :-

The radiation pattern was obtained by multiplying the array factor by the element pattern. It is shown in the attached plot.

3.5 8 Element Linear Array as a test piece :-

To verify the design of the 8×8 elements planar array , a 8 element linear array was designed. Details of the same are furnished below:-

Length of the array L $=N_d$	: 8×5.5 = 44 cm
No. of helix elements	: 8
Spacing between elements 'd'	: 5.5 cm
Theoretical gain of individual element	: 17 dB
Theoretical gain of the array	: 26 dbi (approx.)
Type of the feed	: Uniform distribution using SSL on glass epoxy substrate of 0.4 mm thickness.

The array factor for 8 elements linear array , theoretical element pattern and theoretical radiation pattern are shown in the attached plots. The measured element pattern and radiation pattern are given in next chapter. Theoretical HPBW for the above array [15] comes out to be,

$$\theta_{HP} = 0.886(\frac{\lambda}{L}) \csc\theta_0$$

$$= 0.886\frac{\lambda}{L}$$

$$
\begin{aligned}
&= 0.886\frac{2.53}{38.5} \\
&\approx 3^{\circ}
\end{aligned}
$$

The radiation pattern of the 8×8 planar array can be found by multiplying the array factor of the 8 elements linear array and radiation pattern of the 8 elements linear array (as obtained above).

Chapter 4

Fabrication and measurements

Fabrication of the array was carried out in following steps :-

1. Measurement of ϵ_r of the substrate.

2. Element fabrication and measurements.

3. Array fabrication and measurements.

Each of above are described in following sections.

4.1 Evaluation of ϵ_{reff} of the proposed substrate:-

A large number of methods have been devised over the years to measure dielectric properties at microwave frequencies [16,17,18]. In suspended strip line (SSL) circuits the electric field is nearly perpendicular to the plane of laminate. Therefore a method employing actual SSL circuit was devised to achieve more accurate results. However the accuracy of the method the method was not investigated. The simple method for determination of ϵ_{reff} appear to be those depending on wavelength as determined by the SSL resonant sections. The dielectric loss can be found by measuring the Q of the resonant circuit. Since ϵ_{reff} and loss tangent both can be obtained by SSL resonant circuit, the method is most general. A typical test fixture as shown in the Fig.4.1 was prepared.

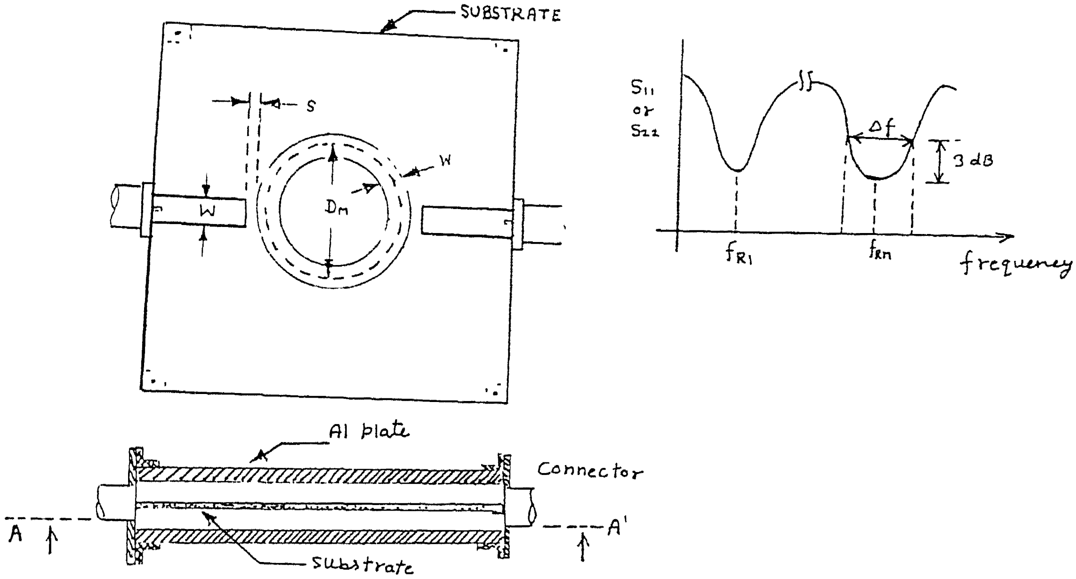


Fig.4.1: Dielectric constant measurement fixture

A number of resonant suspended strip line sections (like straight strip resonators, filter sections, ring resonators, etc.) are possible of which the ring resonator was used. In straight strip resonators, the fringing field at ends extends over the length of the line. This apparent increase in the length needs fringing corrections to be taken into account This is not a problem with ring resonator circuits. The dimensions of the resonator made are given below:-

Resonator length	: 4 λ_g
Strip width	: 2.3 mm
Coupling gap S	: 0 8 mm
Mean dia.of ring D_{min}	: 27.61 mm
Size of the substrate piece	: $80 \times 80 mm^2$
Size of the enclosure	: $80 \times 80 mm^2$

(Guide wavelength $\lambda_g = 21.688$ mm was taken corresponding to assumed $\epsilon_{reff} = 4$.)

The resonance was obtained by varying the input signal frequency and by observing the deep in S_{11} or S_{21} on the scope of the Network analyser. The method is based on the principle that a given circumference of SSL ring will resonate at some frequency for which its effective length 'L' is equal to an integral multiple of guide wavelength lamdag. Therefore at resonance:-

$$\lambda_g = \frac{L}{n} \qquad (4.1)$$

where n is an integer.

Since the guide wavelength,

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{reff}}} \tag{4.2}$$

$$\Rightarrow \epsilon_{reff} = (\frac{nC}{Lf})^2 = (\frac{nC}{\pi Df})^2 \tag{4.3}$$

The accuracy in determining ϵ_{reff} depend on accuracy with which 'f' and 'L' can be measured. The small gap 's'= 0.8 mm lightly couples the ring to the two SSL sections. The resonance frequency was measured by observing the mimima in S_{11} or maxima in S_{21}. A more accurate value of 'f_r' can be found from

$$f_r = \frac{f_{rm}}{1 - \frac{1}{2Q}} \tag{4.4}$$

where f_{rm} is the measured frequency and loaded Q of the ring resonator is given by:-

$$Q = \frac{f_r}{\Delta f} \tag{4.5}$$

where Δf is 3 dB bandwidth. The unloaded Q is given by,

$$Q_{unloaded} = \frac{Q}{1 - \sqrt{T}} \tag{4.6}$$

where T is the power insertion loss ratio = output power/incident power.

The unloaded Q must be used to find more accurate value of resonant frequency. The loss tangent is determined from:-

$$\tan\delta = \frac{1}{Q_{unloaded}} - \frac{1}{Q_c} \tag{4.7}$$

where Q_c is the Q of the copper alone and $1/Q_c = 0.0006$.

Experimental results :-

Since the ring circumference was four fold of λ_g, there were four resonant frequencies (as tabulated below) of which obviously the fourth one was of interest.

Resonance	frequency in GHz.	3 dB bandwidth in GHz
First resonance 'f_1'	2.93532	-
Second resonance 'f_2'	5.90422	0.0568
Third resonance 'f_3'	8.8379	0.0513
Fourth resonance 'f_4'	11.6550	0.164

λ_g at the fourth resonance was calculated. Then several values of ϵ_r were tried to give guide wavelength corresponding to the ring resonator dimension ($4\lambda_g$) at 11.655 GHz. $\epsilon_{eeff} = 3.8$ was found most appropriate. Then the data sheet for SSL for several values of characteristic impedances (attached in appendix) was prepared. For this,the software facility available in the local microwave laboratory was utilized.

Based on above the unloaded 'Q' and loss tangent for the proposed substrate were found to be 72 and 0.0134 respectively.

4.2 Element fabrication :-

The helix element designed for the proposed array is a high profile antenna and hence mechanical stiffness is an important factor apart from electrical requirements. As per design data suggested in antenna handbook by Jasik, the dia. of helix conductor should be taken about 2% of wavelength for axial mode of radiation . But it has experimentally been observed that the conductor size is not a critical parameter and for dia. up to 5% of the wavelength, the antenna characteristic remains lmost unchanged. Therefore few specimens helixes made of enamelled copper conductor of sizes varying from 0.5 mm to 1.5 mm were made. Their electrical characteristics (reflection coefficient, radiation pattern) were found similar. From mechanical stiffness point of view, conductor dia. of 1.5 mm was finalised for the fabrication of elements of array. After few experiments, following mechanical dimensions were derived for the helix :-

Conductor dia.	d = 1.5 mm
Diameter of helix	D = 7.5 mm
Spacing between turns	S = 5.5 mm
Circumference	C = 23.5 mm
Pitch angle	$\alpha = 13°$
No. of turns	N = 14
Length of helix	L = 78 mm

With the above data, helix was supposed to provide following:-

Input impedance

$$Z_{helix} = 140\Omega \pm 10\%$$

$$\text{Gain G} = 17 \text{ dB}$$

$$\text{HPBW } \beta = 32°$$

$$\text{Reletive phase velocity factor p} = 0.762$$

The test fixture with above dimensions was made as depicted in Fig.4.2

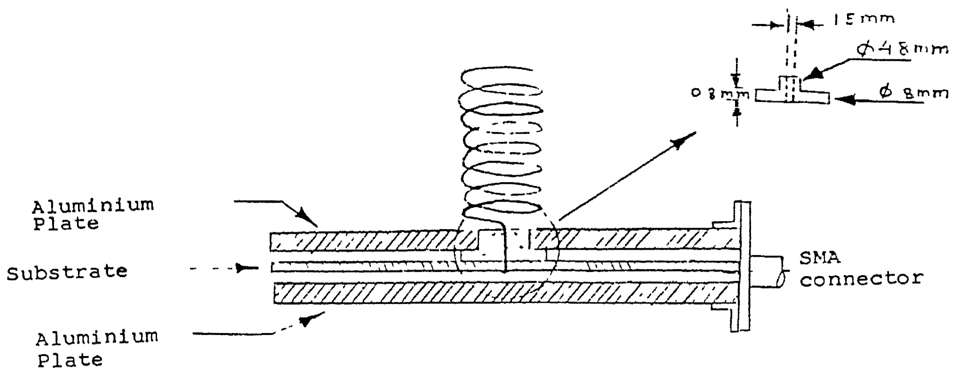


Fig.(4.2) Test fixture and helix

The substrate with 50Ω printed line was placed between two aluminium plates of 1.5 mm thickness and a uniform air gap of 0 5 mm thickness was maintained.on either side of the substrate. A teflon bush of dimensions as shown in fig.(4.2) was used to reduce the sag of the substrate (due to moisture absorption ,etc.) and also to provide mechanical strength to the assembly. The dia. of teflon bush was selected to provide 50 Ω line section of 1.5 mm length. This helps to calculate the impedance at the start of first turn of the helix. Since the inclusion of collar at the end of helix affects the

characteristic impedance of the SSL over a small length (equal to radius of collar = 4 mm) near to feed end of helix the impedance at the start of teflon collar was computed and it was regarded as impedance of the element. The comparison of theoretical and measured parameters of the element is presented in next paragraphs with respect to following points:-

1. Radiation pattern.
2. Input impedance.
3. Axial ratio.
4. Gain.

4.2.1 Radiation pattern :-

The normalised radiation pattern for axial mode helical antenna is given by[12,13]:-

$$E = \sin(\frac{\pi}{2N}) * \frac{\sin N\psi/2}{\sin\psi/2} * \cos\phi \tag{4.8}$$

where N is no. of turns and ϕ is off axis angle and

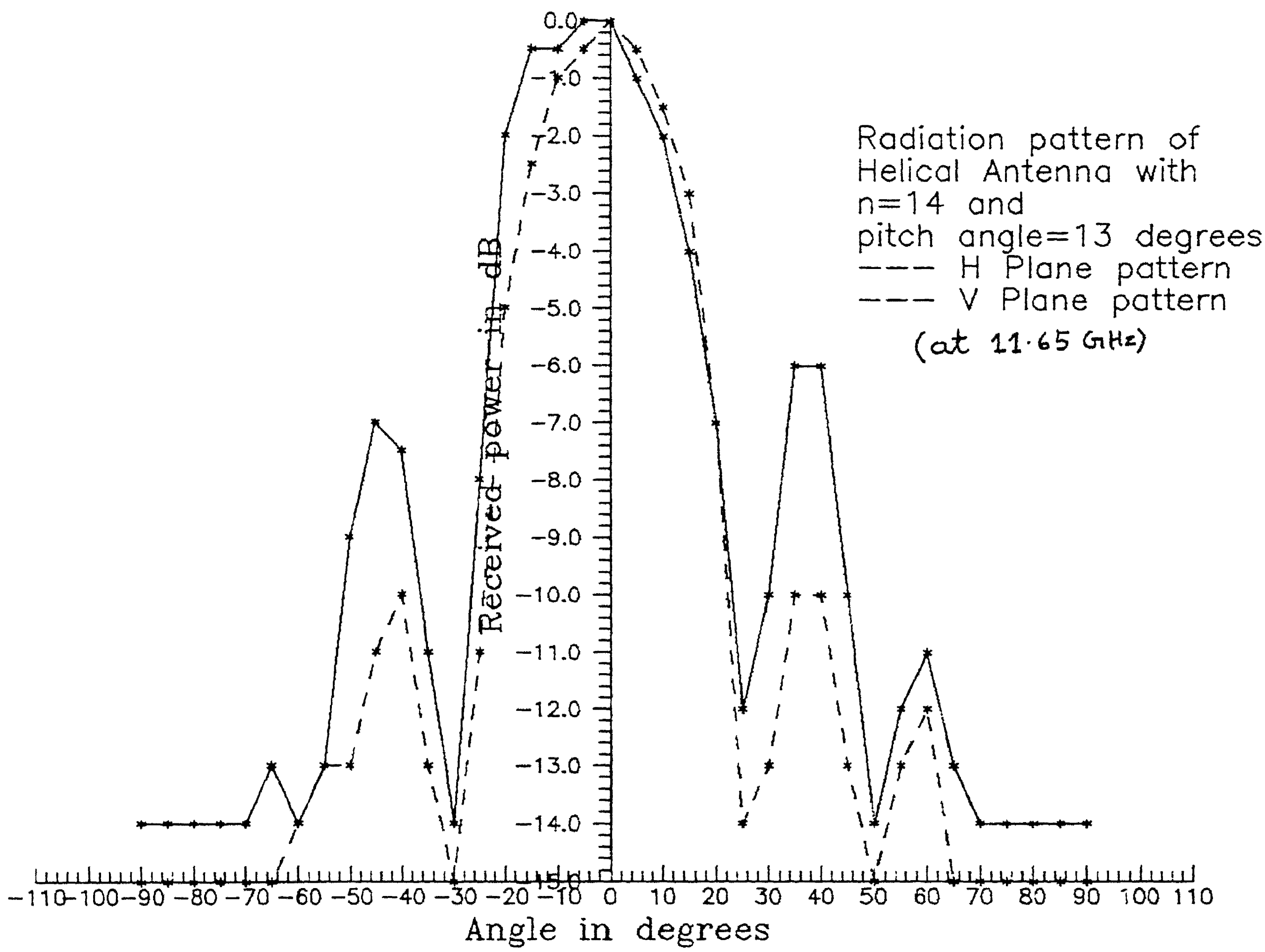
$$\psi = 2\pi(\frac{S}{\lambda}(1 - \cos\phi) + \frac{1}{2N})$$

The theoretical and measured radiation patterns for the designed helix are given in attachaed plots.

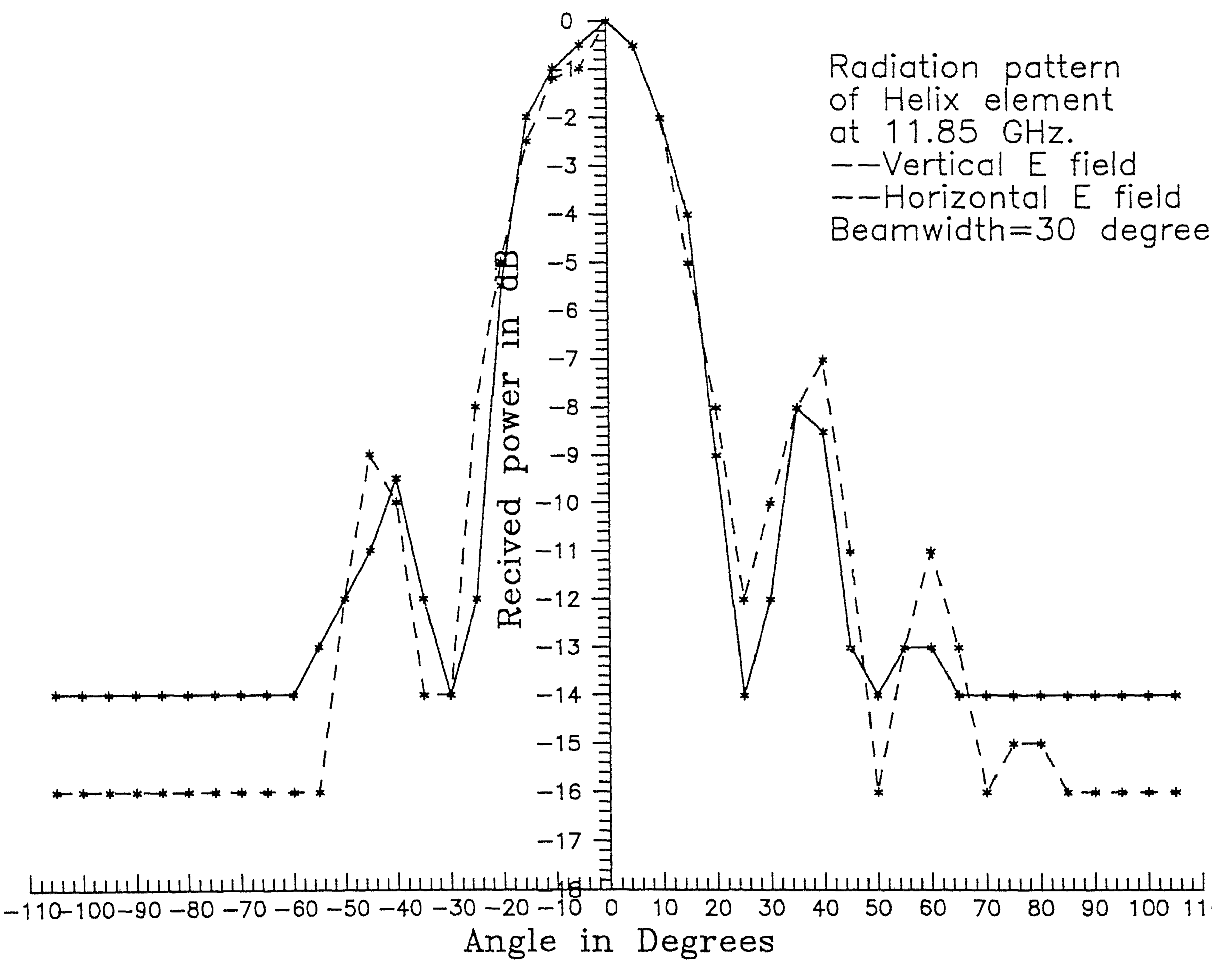
4.2.2 Input impedance :-

The input impedance for the axial mode of radiation of helix over the frequency range for which $3/4 < C/\lambda < 4/3$ (i.e. for the proposed helix 9GHz < f <15.8 GHz.), is given by:-

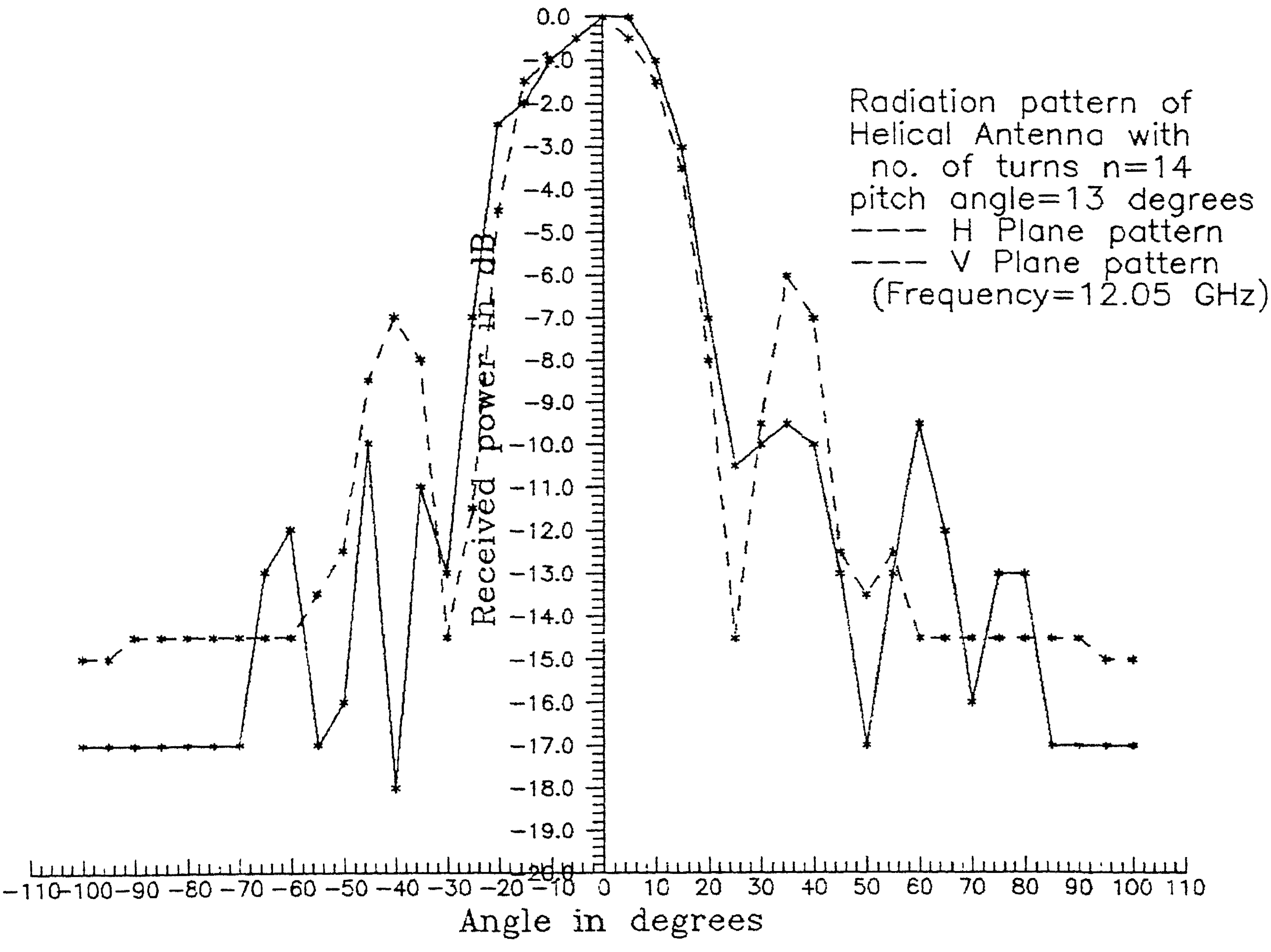
$$R = \frac{140}{\lambda} * C \pm 10\%$$



Radiation pattern of
Helical Antenna with
n=14 and
pitch angle=13 degrees
--- H Plane pattern
--- V Plane pattern
(at 11·65 GHz)
Received power in dB
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
-110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
Angle in degrees



Radiation pattern
of Helix element
at 11.85 GHz.
--Vertical E field
--Horizontal E field
Beamwidth=30 degree
Recived power in dB
Angle in Degrees
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100



Radiation pattern of
Helical Antenna with
no. of turns n=14
pitch angle=13 degrees
--- H Plane pattern
--- V Plane pattern
(Frequency=12.05 GHz)
Received power in dB
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
-16.0
-17.0
-18.0
-19.0
-20.0
-110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
Angle in degrees

This was verified for the proposed element at 11.85 GHz. using a SSL of $Z_0 = 50\Omega$ printed on a low loss substrate (RT Duroid 5880, $\epsilon_r = 2.2$ and $\tan\delta = 0.0015$). The impedance measured at 11.85 GHz, at soldered joint was found (18.6-j21.4)Ω and at the start of helix it was found about 150 Ω (nearly resistive) which agrees with the helix impedance revealed by Kraus. In the above measurement the discontinuity due to small air gap of 0.8 mm was ignored.

In the similar way the helix impedance at 11.85 Ghz frequency, at soldered joint, was determined experimentally using Glass epoxy substrate (0.4 mm thickness). It was found to be 36.5+j23Ω. The measured impedance of the element was matched by providing a matching section (for 11.85 GHz) as shown in Fig. 4.3 below.

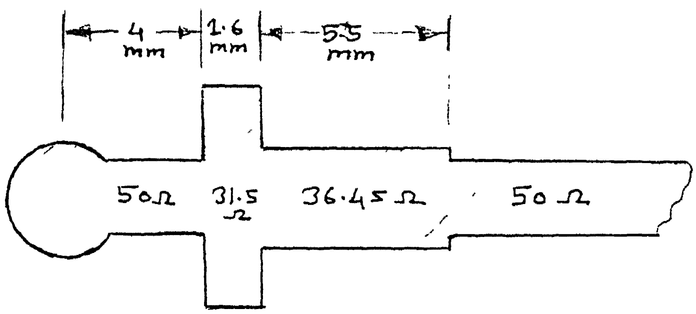
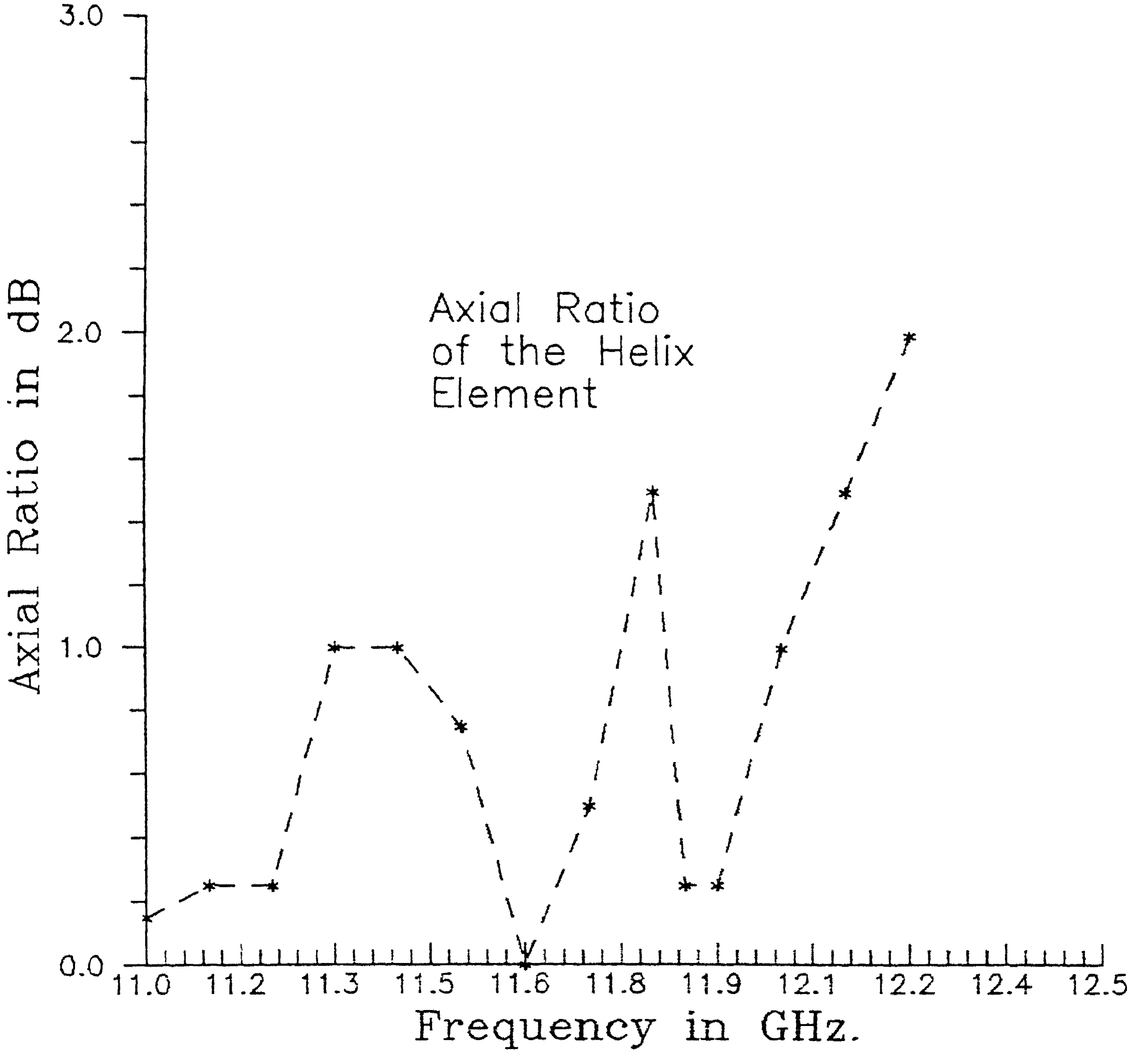


Fig.4.3: Matching section for the helix element

4.2.3 Axial Ratio :-

A linearly polarised wave was created by a horn antenna and power received by the helix was measured. Then the helix fixture was rotated by 90° and again the power received was measured. The difference in the powers received (axial ratio) in the two cases was calculated. The procedure was repeated for few frequencies in 11.0 GHz to 12.2 GHz band. plot of axial ratio v/s frequency is attached. Axial ratio(AR) as suggested by Kraus (ref.) is given by $\frac{2N+1}{2N}$. For N=14 it comes out to be 0.152 dB.


Axial Ratio of the Helix Element
Axial Ratio in dB
Frequency in GHz.
3.0
2.0
1.0
0.0
11.0
11.2
11.3
11.5
11.6
11.8
11.9
12.1
12.2
12.4
12.5

4.2.4 Gain :-

The gain of the helix was measured by **gain transfer method**. The gain of the helix was measured by comparing the power received by standard horn antenna of known gain and power received by the helix. This method requires a gain standard with which gain of test antenna is compared. Once the comparison has been performed the gain of the standard antenna is said to have been transferred to the test antenna. After mounting the test antenna properly the received power P_{tr} was measured. The test antenna was then replaced by the standard antenna and again the received power P_{sr} was measured. The gain of the test antenna was then calculated from the following expression:-

$$(G_T)_{dB} = (G_s)_{dB} + 10\log\frac{P_{T_r}}{P_{sr}} - 10\log\frac{q_T}{q_s} - 10\log\frac{P_T}{P_s} \tag{4.9}$$

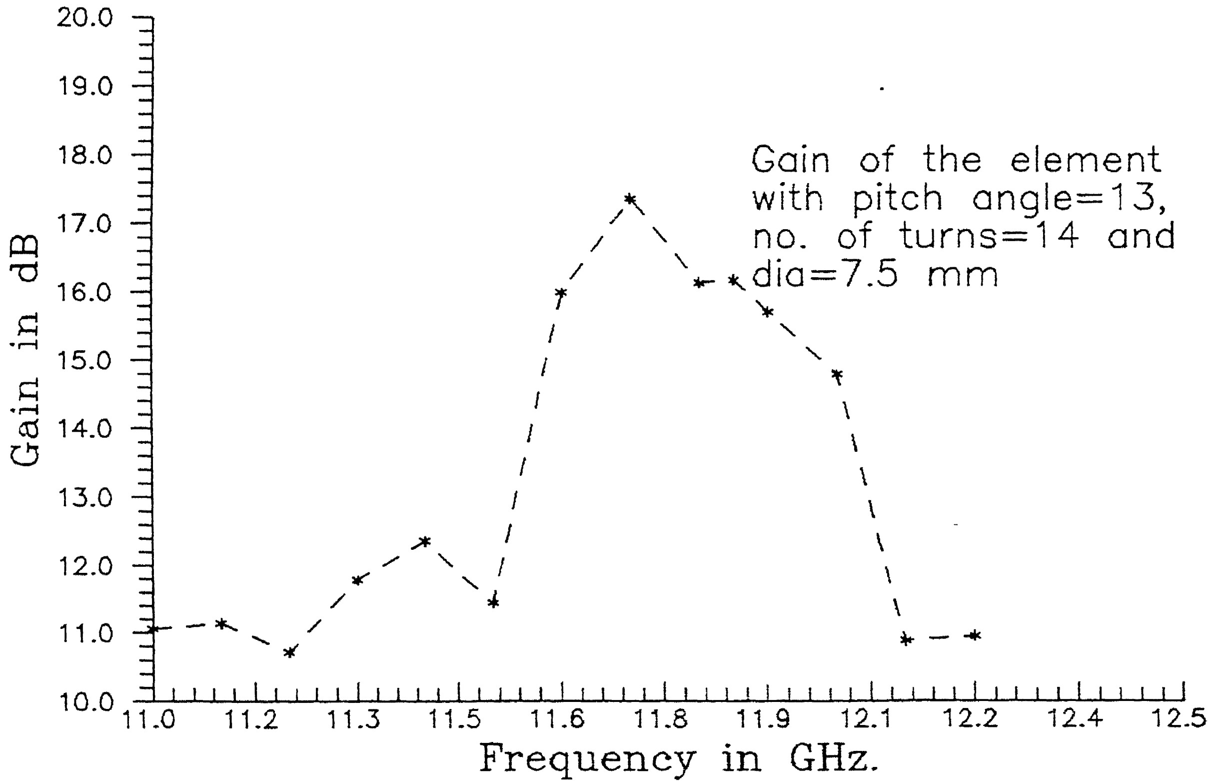
where q_t, q_s are impedance mismatch factors of test antenna and standard antenna; P_t, P_s are polarization efficiencies respectively.

For the present case of circular polarization the measurements were accomplished by measuring the partial gains of the test antenna with respect to two orthogonal orientations of gain standard antenna. This resulted in measurements of partial gains G_{tv} (for vertical polarization) and G_{th} (for horizontal polarization). Then the actual gain can be found from

$$G_t)_{db} = 10\log(G_{tv} + G_{th}) \tag{4.10}$$

The finite axial ratio (AR) of a linearly polarised wave, emanated from the horn antenna, introduces some error in the measurements which is to be substracted. The error normally ranges from ±0.8 dB to ±0.03dB depending on the axial ratio of the wave from the source [14].

The results of gain measurements are given on the next page and the gain v/s frequency plot is attached.


Gain of the element
with pitch angle=13,
no. of turns=14 and
dia=7.5 mm
Gain in dB
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
11.0
11.2
11.3
11.5
11.6
11.8
11.9
12.1
12.2
12.4
12.5
Frequency in GHz.

Frequency in GHz	Gain in dB
11.0	11.06
11.1	11.14
11.2	10.72
11.3	11.80
11.4	12.37
11.5	11.45
11.6	16.02
11.7	17.40
11.8	16.17
11.85	16 21
11.9	15.74
12.0	14.82
12.1	10.89
12.2	10.96

4.3 Array fabrication :-

The design details of the 64 elements DBS array are as under:-

Mechanical details :-

Size of aluminium ground plates	: 60 x 60 cm cm
Thickness of Al. ground plates	: 1.5 mm
No. of holes in upper plate as per elements disposition	: 64
Dia. of holes to accommodate teflon bushes	: 5 mm
Total no. of teflon bushes	: 64
Size of substrate	: 60×60 cm^2
Thickness of substrate	: 0.4 mm
Required qty. of studes and nut pairs	: 100 nos.
Air gap on either side of the substrate	: 0.8 mm
No. of insulating spacers of 0.8 mm thickness	: 200 nos.
No. of insulating spacers of type-2 (0.8 mm thickness)	: 64 nos.
SMA connectors	: 1 no.
Brackets of appropriate size to mount the SMA connector	: 2 nos.

Electrical details :-

Overall gain of array	: 35 dBi (approx.)
Gain of individual element	:17 dBi (approx.)
No. of helix elements	:64 nos.
Interelement spacing	: 5.5 cm
Polarization	: Circular
Axial ratio	: < 3 dB
Frequency range	: 11.5 GHz.- 12.0 GHz.

To verify the above designe a test piece of linear array comprising 8 elements was prepared. The comparison of theoretically calculated and practically achieved parameters like radiation pattern, gain, beamwidth and axial ratio are given on next sections.

4.3.1 Radiation pattern :-

The expected radiation pattern of 8 elements linear array and practically measured radiation patterns as shown in attached plots which are more or less similar. Thus the design is acceptable for two dimensional array.

4.3.2 Gain :-

The theoretically calculated gain of the array is about 26 dB. The plot of measured gain v/s frequency is attached.

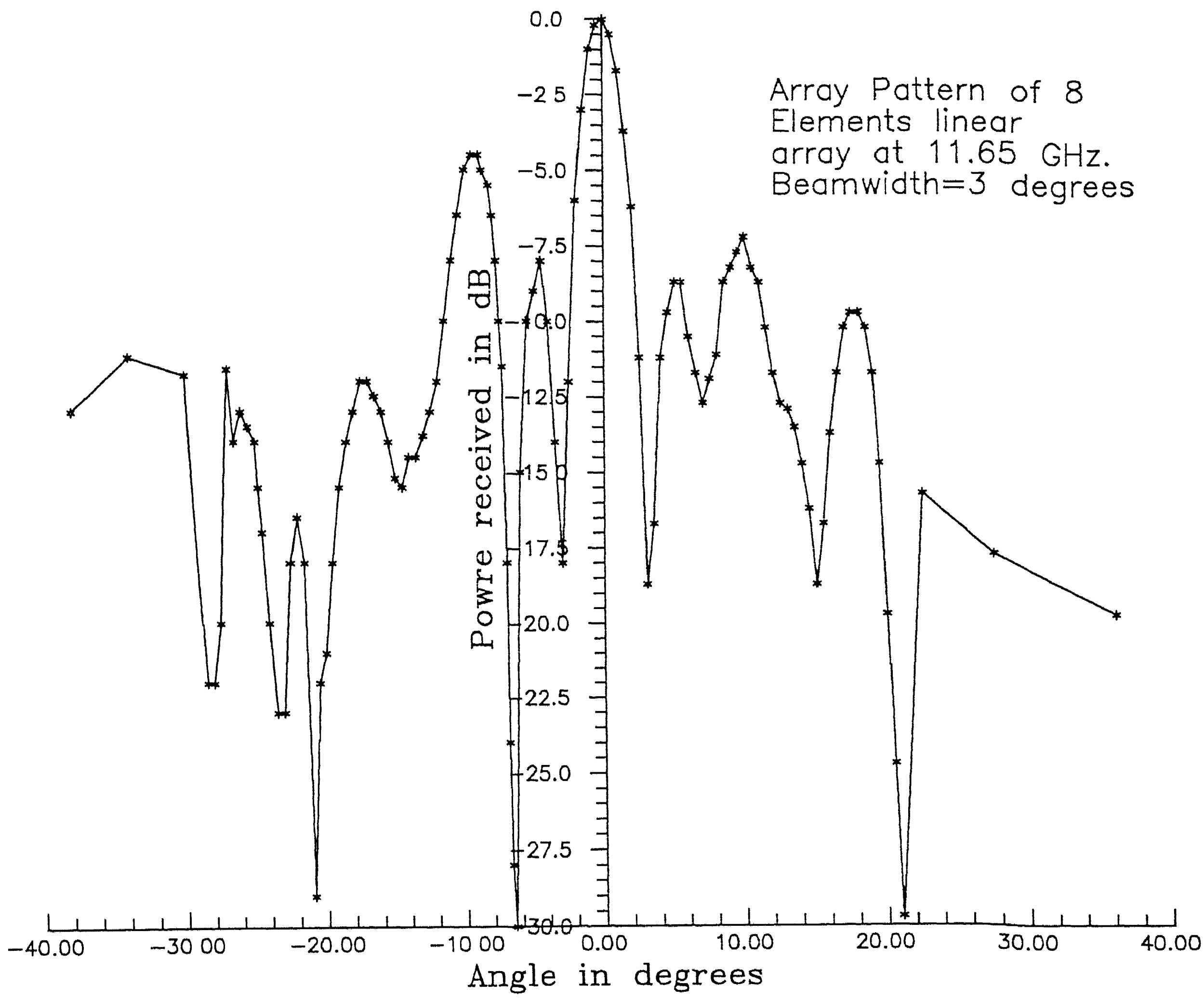
4.3.3 Beamwidth :-

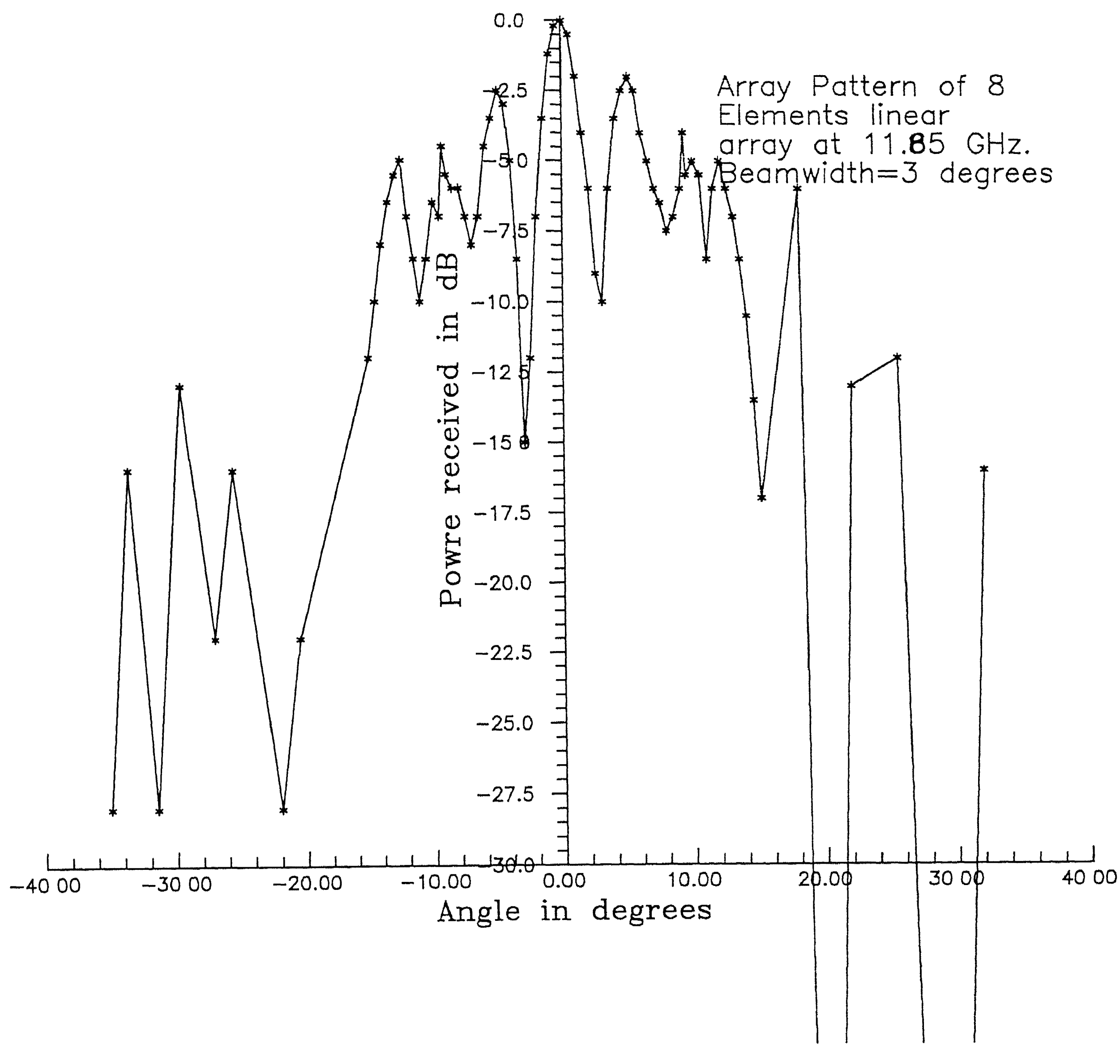
The calculated 3 dB beamwidth for linear array is given by [14]:-

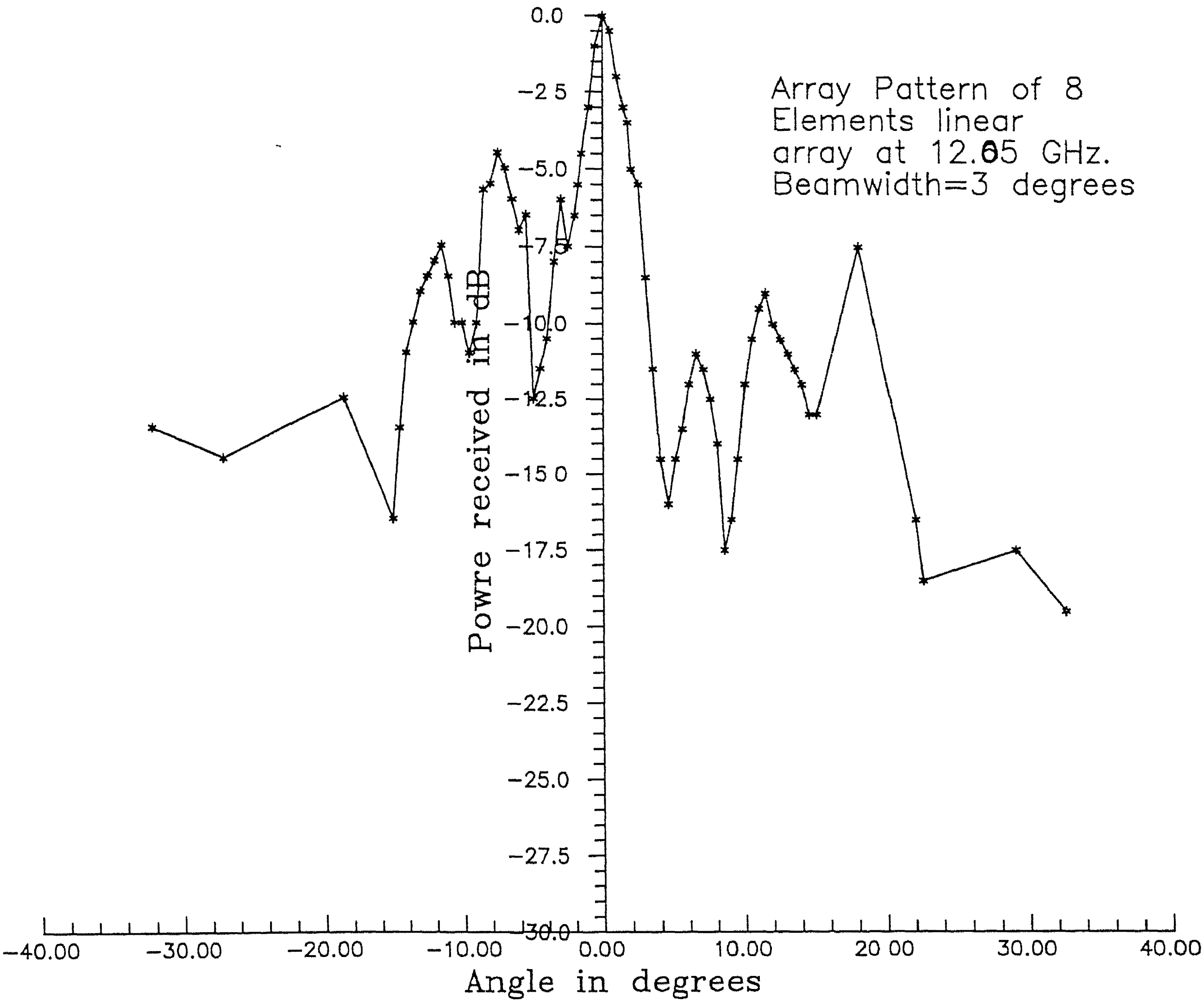
$$\beta = 0.886\frac{\lambda}{L}rad \tag{4.11}$$

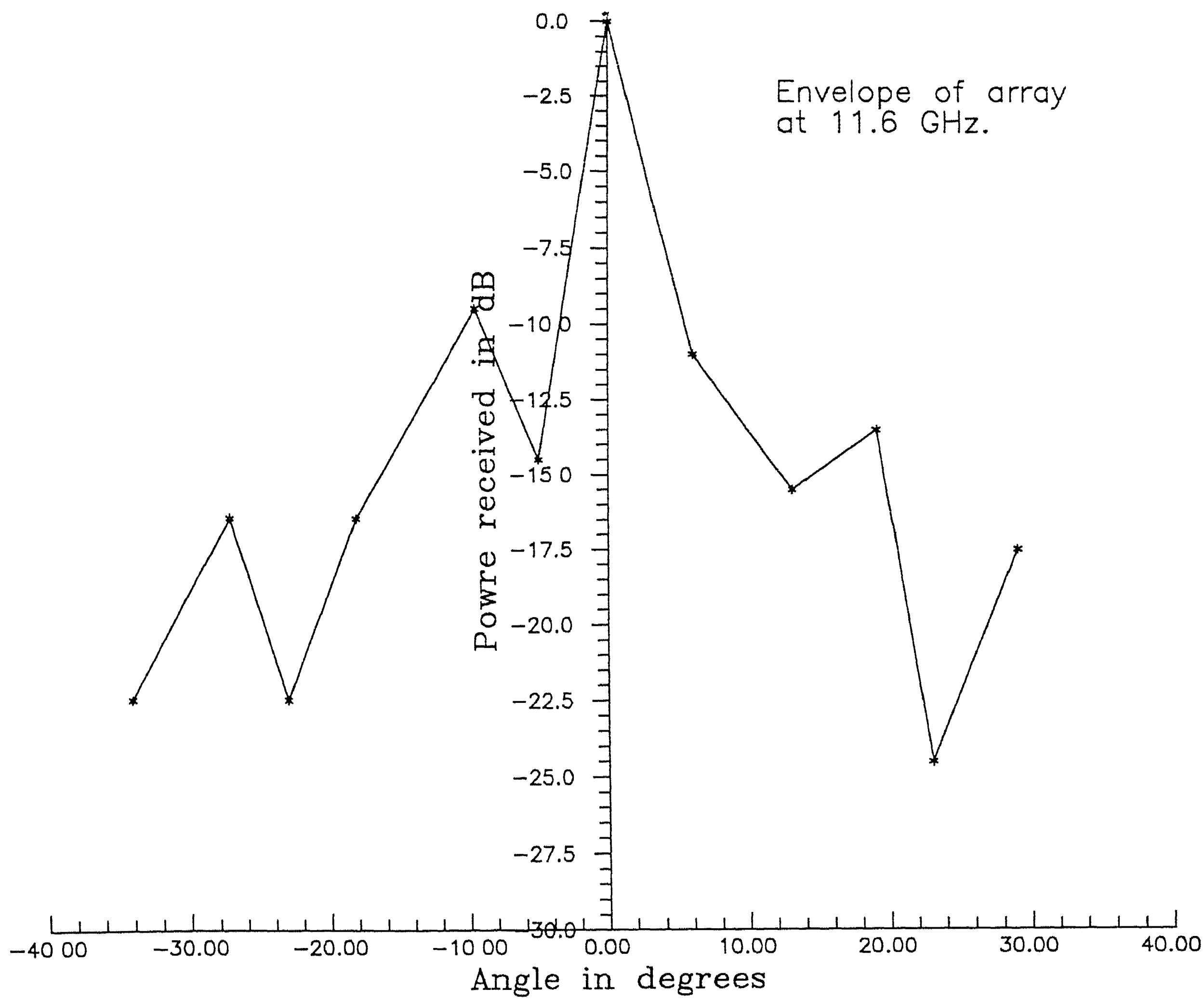
From which β =0.886(2.53/45) = 3°

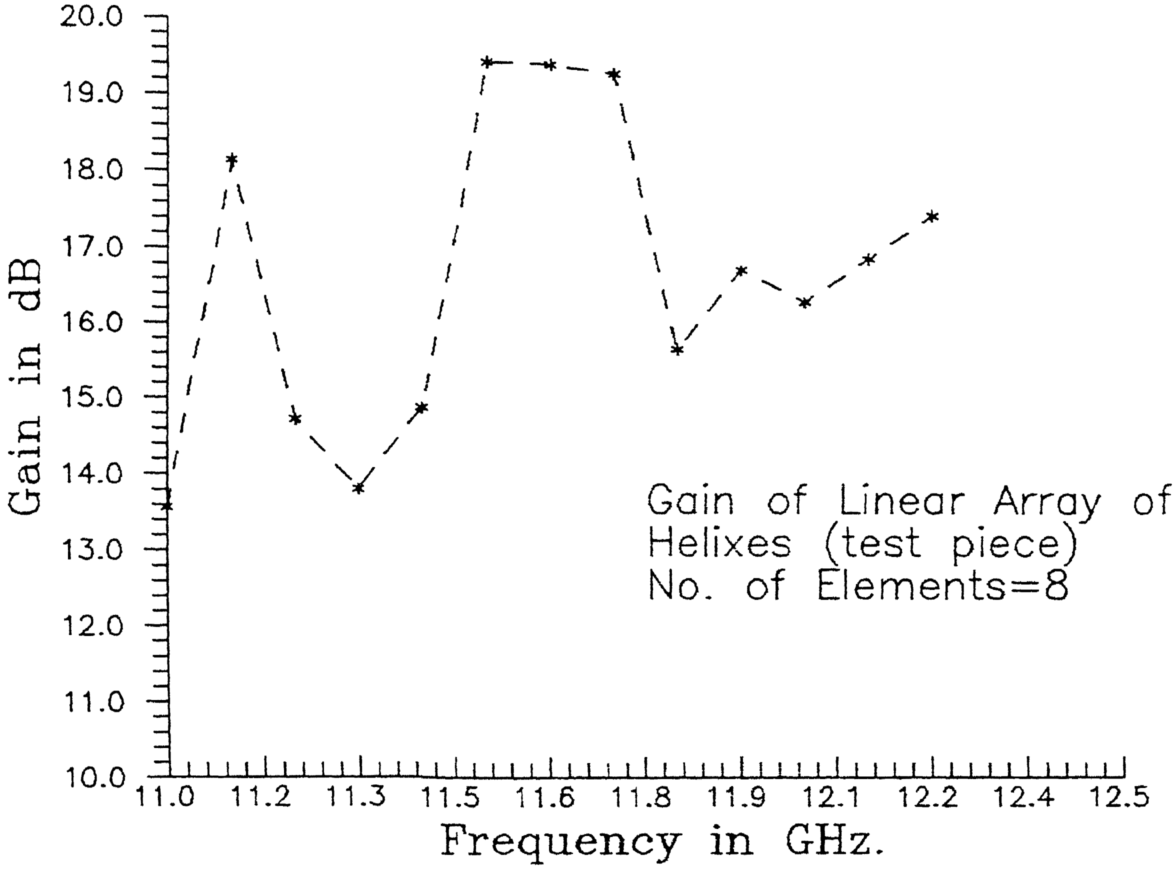
The measured HPBW at 11 65 GHz, 11.85 GHz and 12.05 GHz are 3° 32° in the two principle planes.


Array Pattern of 8
Elements linear
array at 11.65 GHz.
Beamwidth=3 degrees
Powre received in dB
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-40.00
-30.00
-20.00
-10.00
0.00
10.00
20.00
30.00
40.00
Angle in degrees


Array Pattern of 8
Elements linear
array at 11.85 GHz.
Beamwidth=3 degrees
Powre received in dB
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-40 00
-30 00
-20.00
-10.00
0.00
10.00
20.00
30 00
40 00
Angle in degrees


Array Pattern of 8
Elements linear
array at 12.65 GHz.
Beamwidth=3 degrees
Powre received in dB
Angle in degrees
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-40.00
-30.00
-20.00
-10.00
0.00
10.00
20.00
30.00
40.00


Envelope of array
at 11.6 GHz.
Powre received in dB
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
-27.5
-30.0
-40.00
-30.00
-20.00
-10.00
0.00
10.00
20.00
30.00
40.00
Angle in degrees



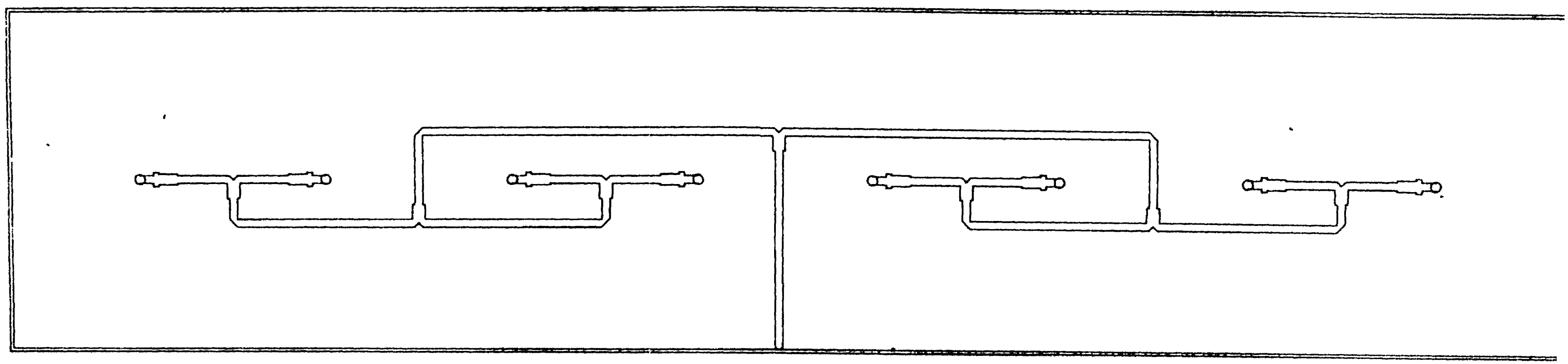
Gain in dB
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
11.0
11.2
11.3
11.5
11.6
11.8
11.9
12.1
12.2
12.4
12.5
Frequency in GHz.
Gain of Linear Array of
Helixes (test piece)
No. of Elements=8

4.3.4 Axial ratio (AR) :-

The measured axial ratio in the frequency range of 11.5 GHz. to 12 GHz. was found within 2 dB. However through investigation of axial ratio was not carried out as it is a very sensitive parameter and its measurement requires very accurate determination of radiation patterns in the two principle planes. This can be carried out in a suitable anechoic chamber.

Feed for the array :-

The feed network for uniform power distribution was designed for test array . Impedance matching sections were incorporated into the feed network itself. Appropriate compensation for discontinuities at right angle bends, T-junctions, etc. were suitably compensated. The details of compensations are given in appendix. Layout of uniform feed networks for 8 elements array, linear array is attached.



8 Element feed network for linear array

Chapter 5

Results, Discussion and Scope for Further work

5.1 Results :-

The results of the experiments carried out are summarised below:-

The designed helix element provides following parameters in the frequency range 11.5 GHz to 12 GHz :

Average Gain	. 16 dB
Axial ratio	: 0 to 1.5 dB
3 dB beamwidth β	: 32°
Mismatch loss	: 0.4 dB

The 8 element linear array (test piece) exhibits following in the operating range of frequency:-

Gain	: 17 dB to 19 dB
Axial ratio	: 0 to 1.5 dB
3 dB beamwidth θ_H	: 3°
3 dB beamwidth θ_V	: 32°
Directivity	: 26 dbi
Efficiency η	: 20%(approx.)

Based on above the overall gain of the array would be about 26 dBi to 28 dBi (approx.) instead of 35 dBi.

5.2 Discussion :-

The array was designed to provide a gain of 35 dBi and the 8 element linear array (test model) should have provided a gain of about 26 dBi. The reduction in gain by about 7 dBi could be due to higher losses in the feeder. The measured loss tangent of

the proposed substrate at the operating frequency was found to be 0.0134. Based on strip line analysis [17] the dielectric filling factor $q_{\tan\delta}$ and attenuation factor α_d (in dB per cm) were calculated and are given below:-

$$q_{\tan\delta} = \frac{\epsilon_{reff} - 1.0}{\epsilon_{reff} - \frac{\epsilon_{reff}}{\epsilon_r}}$$

and

$$\alpha_d = 0.91 q_{\tan\delta} \tan\delta \sqrt{\epsilon_{reff}} f$$

where 'f' is in GHz.

For the proposed substrare α_d comes out to be 0.05848 dB/cm and the total dielectric losses associated with the feeder network were found 2 dB (approx.). The remaining 5 dB decline in the gain (from the expected one) could be due to other losses (radiation losses and ohmic losses) and poor antenna aperture efficiency. Some improvement in the gain can be acheived by increasing the aperture area.

The actual gain of the array and element can be measured in an anechoic chamber. The results given above are based on the experiments performed in non anechoic envoirnment. The effects of reflections from nearby walls and other objects introduces errors in the measurements . Therefore the results given above may differ from the actual values.

5.3 Scope for further work :-

The design of the array can be improved with respect to following points:-

- Reduction in losses
- Reduction in weight of the array .
- Reduction in height by employing low profile helical elements.
- Reduction in feeder losses.

- Provision of beam-tilt

Feeder losses can be overcome up to certain extent by increasing the aperture area. Increase in aperture area will accout for more losses due to increase fedder length. Study can be carried out to observe weather the increase in aperture area can overcome the feeder losses or not.

Polypropelene substrate can be tried in place of glass epoxy substrate which is available at lower cost compared to Duroid-5880, PTFE, etc. If a radial waveguide is used instead of the substrate, then the losses can be reduced to a reasonable extent but it will increase the weight of the antenna [5,6,7,8]. An special light weight radial waveguide can be designed to suit the application. The fabrication of the waveguide and positioning of helical elements would involve high accuracy.

Weight and cost can be reduced reduced by using thin aluminium sheets (approx. 0 5 mm) instead of 1.5 mm thick sheet. The height of the array can be reduced if low profile helixes are used as array elements. Since the low profile helix has lower gain and broad radiation pattarn [6,7], the feed network will become complex as total number of elements will increase and non uniform distributon will be required to reduce the grating lobes. The increase in feeder loss can be compensated by employing larger number of elements and/or by increasing the aperture area.

Other substrates available at lower cost can be tried with this type of arrangement to find a better substitute of proposed substrate.

Since the distance between elements in the proposed is more than twice the operating wavelength , the effect of mutual coupling was ignored. However the same can be investigated.

The possibility of incorporating beamtilt facility can also be explored. It has been reported in the literature [7] that beam tilt can be provided by turning the elements about their axis. The relation between the amount of the rotation and beamtilt can be investigated.

Appendix

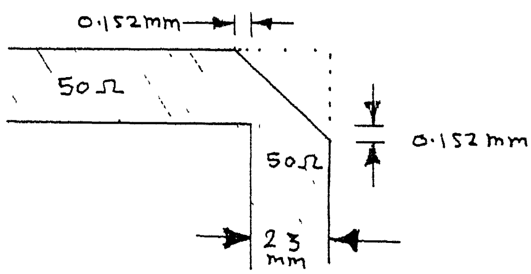
A.1:Characteristics of some important substrates at X-band:-

Substrate	Dielectri constant	Loss tangent	Cost
Polytetrafluoro-ethelene	2.10	0.0004	High
Polypropelene	2.18	0.0003	Low
Modified Polyethylene	2.3	0.0002	Low
Polyphenylene oxide	2.6	0.002	Medium
RT-duroid 5880	2.16-2.24	0.0005-0.0015	High
RT-duroid 6010	10.2-10.7	0.001-0.006	High

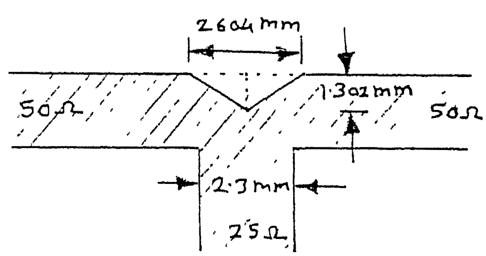
A.2: Compensation for discontinuities :-

Following compensated sections were designed and incorporated in the feed network of the array . These are based on compensation techniques for stripline discontinuities [18].

(i)Right angle band:-



(ii) T-Junction:-



A.3: Data for suspended stripline on glass epoxy substrate :-

Data for suspended microstrip line

ers	=	3.8000000	
era	=	1.0000000	
d	=	0.4000000	mm
h1	=	0.8000000	mm
h2	=	0.8000000	mm
b	=	2.0000000	mm
c	=	80.0000000	mm
d/b	=	0.2000000	
freq.	=	11.8500000	GHz

w(mm)	w/b	ereff	lamda(mm)	Z(ohms)	cf(pF)
0.300	0.150	1.720	19.305	128.182	13.924
0.400	0.200	1.672	19.578	116.922	14.263
0.500	0.250	1.632	19.816	108.145	14.477
0.600	0.300	1.598	20.028	100.956	14.614
0.700	0.350	1.568	20.217	94.873	14.701
0.800	0.400	1.542	20.389	89.608	14.755
0.900	0.450	1.518	20.545	84.978	14.787
1.000	0.500	1.498	20.687	80.854	14.802
1.100	0.550	1.479	20.817	77.146	14.807
1.200	0.600	1.462	20.937	73.787	14.803
1.300	0.650	1.447	21.048	70.723	14.793
1.400	0.700	1.433	21.151	67.915	14.780
1.500	0.750	1.420	21.246	65.329	14.763
1.600	0.800	1.408	21.335	62.939	14.744
1.700	0.850	1.397	21.418	60.721	14.723
1.800	0.900	1.387	21.496	58.658	14.700
1.900	0.950	1.378	21.569	56.732	14.676
2.000	1.000	1.369	21.638	54.931	14.652
2.100	1.050	1.361	21.702	53.241	14.627
2.200	1.100	1.353	21.763	51.654	14.601
2.300	1.150	1.346	21.821	50.160	14.574
2.400	1.200	1.339	21.876	48.750	14.547
2.500	1.250	1.333	21.928	47.418	14.520
2.600	1.300	1.327	21.977	46.157	14.492
2.700	1.350	1.321	22.025	44.963	14.463
2.800	1.400	1.316	22.069	43.828	14.435
2.900	1.450	1.311	22.112	42.750	14.406
3.000	1.500	1.306	22.153	41.724	14.377
3.100	1.550	1.301	22.192	40.746	14.347
3.200	1.600	1.297	22.230	39.813	14.318
3.300	1.650	1.293	22.266	38.922	14.288
3.400	1.700	1.289	22.301	38.070	14.258
3.500	1.750	1.285	22.334	37.254	14.228
3.600	1.800	1.281	22.366	36.473	14.198
3.700	1.850	1.278	22.396	35.724	14.168
3.800	1.900	1.274	22.426	35.005	14.137
3.900	1.950	1.271	22.454	34.315	14.107
4.000	2.000	1.268	22.482	33.651	14.077
4.100	2.050	1.265	22.508	33.012	14.046
4.200	2.100	1.262	22.534	32.398	14.016
4.300	2.150	1.259	22.558	31.805	13.986
4.400	2.200	1.257	22.582	31.234	13.955
4.500	2.250	1.254	22.605	30.683	13.925
4.600	2.300	1.252	22.628	30.151	13.895
4.700	2.350	1.249	22.649	29.637	13.864
4.800	2.400	1.247	22.670	29.141	13.834
4.900	2.450	1.245	22.691	28.660	13.804
5.000	2.500	1.243	22.710	28.196	13.774
5.100	2.550	1.241	22.729	27.745	13.744
5.200	2.600	1.239	22.748	27.309	13.715

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